Chapter 8: Vibrations and Waves

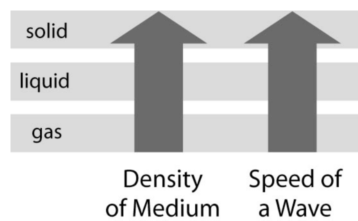
Mini Investigation: Observing Wave Motion, page 377

A. During the first type of movement, the Slinky moved back and forth across the line it originally made on the table. During the second type of motion, the Slinky stayed on the line, but the coils of the Slinky got closer together then farther apart.
B. When the far end was free, the Slinky moved from side to side during the first movement and in and out during the second movement.
C. When the far end was fixed, the Slinky did not move and it reflected the waves back to the start of the Slinky.

Section 8.1: What Is a Vibration?

Section 8.1 Questions, page 380

1. Answers may vary. Sample answer:
A vibration is the cyclical motion of an object about an equilibrium point. A wave is the transfer of energy through a material due to vibration. Vibration is the cause and the wave is the effect.
2. Answers may vary. Sample answers:
Five everyday vibrating objects are a swinging pendulum, a stretched elastic band, a skipping rope in motion, a plucked guitar string, and the motion of a tuning fork.
(a) The pendulum swings back and forth across an equilibrium point. Therefore, it is a vibration.
The elastic band vibrates back and forth across an equilibrium point when plucked. Therefore, it is a vibration.
The skipping rope swings around an equilibrium position. Therefore, it is a vibration.
A plucked guitar string vibrates back and forth about its equilibrium position. Therefore, it is a vibration.
The tuning fork vibrates about its equilibrium position. Therefore, it is a vibration.
(b) Since the particles in the elastic band, the guitar string, and the tuning fork are disturbed, those three vibrations transmit a mechanical wave.
(c) The elastic band transmits mechanical waves through itself. The guitar string transmits mechanical waves through itself. The tuning fork transmits mechanical waves through itself.
3. Answers may vary. Sample answer:
The density of the medium allows a wave to pass through most effectively. For example, a tuning fork is a solid with high density, so it sustains vibrations for longer time as waves pass through it more effectively.
4. Answers may vary. Sample answer:
Sonar and radar use waves to detect objects and navigate ships. Mobile phones use waves to send and receive signals. Musical instruments such as guitars and pianos use vibrations to make sounds.
5. Answers may vary. Sample answer:
Earthquakes can be highly destructive mechanical waves. Tidal waves (or tsunamis) can be harmful to boats and people living near the coast.
6. Answers may vary. Sample answer:



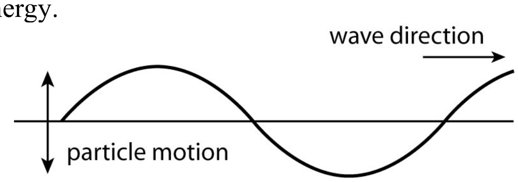
Section 8.2: Types of Mechanical Waves

Mini Investigation: Simulating Transverse and Longitudinal Wave Motion, page 383

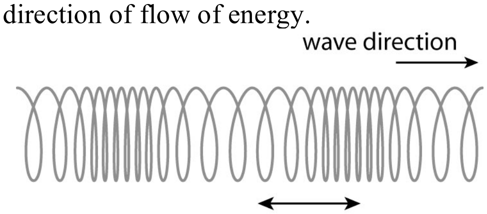
A. In the transverse wave demonstration, when we pass each other, we are still 1 m apart. If that is the *x*-axis, then in the *y*-axis I am always one step behind the person in front of me and one step ahead of the person behind me.
B. The farthest you could move was three steps. In a true medium, this aspect of the wave's motion would be controlled by the density of the medium and the size of the vibration.
C. In the longitudinal wave demonstration, it was difficult to maintain the motion because if we didn't all move at the same time, the people in front and behind me would get in my way.
D. Answers may vary. Sample answer:
The simulations were not fair because the particles did not all return to their equilibrium. Only the first person, fourth person, and so on, returned to their starting points.

Section 8.2 Questions, page 384

1. Answers may vary. Sample answer:
In transverse waves, particles of the medium move perpendicular to the direction of the flow of energy.



In longitudinal waves, particles move parallel to the direction of flow of energy.

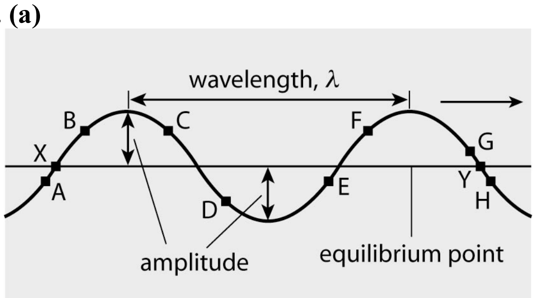


2. Answers may vary. Sample answer:
A vibrating string and a boat in a sea. The string vibrates perpendicular to the direction of energy flow. Similarly, the boat moves up and down, whereas the water waves move perpendicularly to the boat.
3. Answers may vary. Sample answer:
Sound waves and shock waves are examples of longitudinal waves. In these waves, the disturbance travels along the same axis as the motion of the wave.
4. The "wave" is not a true mechanical wave because there is no equilibrium point in the motion. People raise their hands in only one direction. Also, there is no flow of energy, just a simulation to give the appearance of it.
5. Answers may vary. Sample answer:
Longitudinal waves that have properties making them detectable to the human ear are referred to as sound. The energy transferred through successive compressions and rarefactions of a sound wave causes vibrations in our ears that our brain interprets as sound. Sound is transmitted effectively in solids due to their tight molecular arrangement.
6. Yes. Sound is a mechanical wave because it is caused by vibrations of materials.
7. Answers may vary. Sample answer:
Advantages of being able to detect sound include medical uses such as stethoscopes, aesthetic pleasure through musical instruments, and animals detecting food or predators.
8. Answers may vary. Sample answer:
Two examples of complex wave motion are ocean waves and the waves that result when you strike a solid object. The water particles move up and down at the same time as they move back and forth. These are characteristics of longitudinal and transverse waves. When a solid object is struck, the impact creates transverses waves along the surface and longitudinal waves below the surface. In sound waves, the disturbance travels along the same axis as the motion of the wave.
9. Answers may vary. Sample answers:
(a) Sound reduces as the air is removed from the jar and increases as the air is pumped back into the jar.
(b) Sound waves require a medium to move through. As the air is removed from the jar, the density of the medium decreases so the sound decreases.

Section 8.3: Wave Characteristics

Section 8.3 Questions, page 387

1. (a)

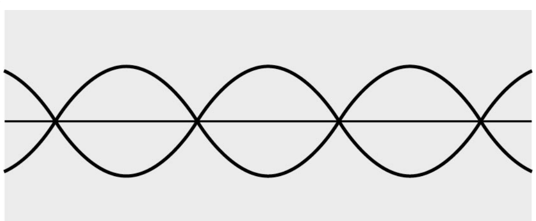


(b) The pairs of points that are in phase are A and E (one wavelength apart), and B and F (one wavelength apart).

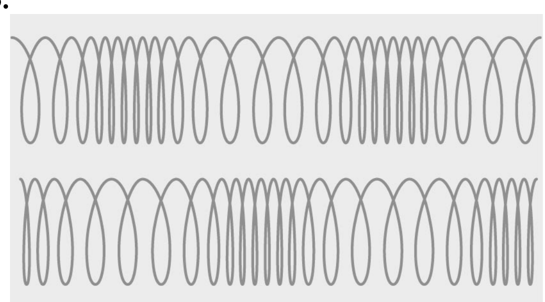
2. In transverse waves, wavelength is the distance between two similar points in successive identical cycles in a wave. In transverse waves, amplitude is the maximum displacement of a vibrating particle in a wave. In longitudinal waves, amplitude is the maximum pressure created and the same definition of wavelength applies.

3. Frequency is the number of times the wave repeats itself in a given time frame, whereas the wave speed is the measure of how far the wave travels per second.

4.



5.



6. Yes, those motions were examples of simple harmonic motion because they were continuous motions with constant amplitude, period, and frequency.

Section 8.4: Determining Wave Speed

Tutorial 1 Practice, page 389

1. Given: f = 230 Hz; λ = 2.3 m

Required: v

Analysis: $v = f\lambda$

Solution:
$$v = f\lambda$$
$$= (230\text{ Hz})(2.3\text{ m})$$
$$v = 530\text{ m/s}$$

Statement: The speed of the wave is 530 m/s.

2. Given: v = 1500 m/s; f = 11 Hz

Required: λ

Analysis:
$$v = f\lambda$$
$$\lambda = \frac{v}{f}$$

Solution:
$$\lambda = \frac{v}{f}$$
$$= \frac{1500\text{ m/s}}{11\text{ Hz}}$$
$$\lambda = 140\text{ m}$$

Statement: The wavelength is 140 m.

3. Given: v = 405 m/s; λ = 2.0 m

Required: f

Analysis:
$$v = f\lambda$$
$$f = \frac{v}{\lambda}$$

Solution:
$$f = \frac{v}{\lambda}$$
$$= \frac{405\ \frac{\cancel{\text{m}}}{\text{s}}}{2.0\ \cancel{\text{m}}}$$
$$f = 2.0 \times 10^2\text{ Hz}$$

Statement: The frequency of the wave is 2.0×10^2 Hz, or 200 Hz.

Tutorial 2 Practice, page 391

1. Given: L = 2.5 m; F_T = 240 N; v = 300 m/s

Required: m

Analysis:
$$v = \sqrt{\frac{F_T}{\mu}}$$
$$v^2 = \frac{F_T}{\mu}$$
$$\mu = \frac{F_T}{v^2}$$
$$\mu = \frac{m}{L}$$
$$m = \mu L$$
$$m = \frac{F_T}{v^2}L$$

Solution:
$$m = \frac{F_T}{v^2}L$$
$$= \frac{240\text{ N}}{(300\text{ m/s})^2}(2.5\text{ m})$$
$$= \frac{240\ \frac{\text{kg}\cdot\cancel{\text{m}}}{\cancel{\text{s}^2}}}{90\ 000\ \frac{\cancel{\text{m}^2}}{\cancel{\text{s}^2}}}(2.5\ \cancel{\text{m}})$$
$$m = 6.7 \times 10^{-3}\text{ kg}$$

Statement: The mass of the string is 6.7×10^{-3} kg, or 6.7 g.

2. Given: μ = 0.2 kg/m; v = 200 m/s

Required: F_T

Analysis:
$$v = \sqrt{\frac{F_T}{\mu}}$$
$$v^2 = \frac{F_T}{\mu}$$
$$F_T = \mu v^2$$

Solution:
$$F_T = \mu v^2$$
$$= (0.2\text{ kg/m})(200\text{ m/s})^2$$
$$= \left(0.2\ \frac{\text{kg}}{\cancel{\text{m}}}\right)\left(40\ 000\ \frac{\text{m}^{\cancel{2}}}{\text{s}^2}\right)$$
$$= 8 \times 10^3\ \frac{\text{kg}\cdot\text{m}}{\text{s}^2}$$
$$F_T = 8 \times 10^3\text{ N}$$

Statement: The tension required is 8×10^3 N, or 8000 N.

3. Given: μ = 0.011 kg/m; F_T = 250 N

Required: v

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

Solution:
$$v = \sqrt{\frac{F_T}{\mu}}$$
$$= \sqrt{\frac{250\text{ N}}{0.011\text{ kg/m}}}$$
$$= \sqrt{\frac{250\ \frac{\cancel{\text{kg}}\cdot\text{m}}{\text{s}^2}}{0.011\ \frac{\cancel{\text{kg}}}{\text{m}}}}$$
$$v = 1.5 \times 10^2\text{ m/s}$$

Statement: The wave speed is 1.5×10^2 m/s, or 150 m/s.

Section 8.4 Questions, page 391

1. Given: v = 123 m/s; f = 230 Hz

Required: λ

Analysis: $v = f\lambda$

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

Solution: $\lambda = \frac{v}{f}$

$$= \frac{123 \text{ m/s}}{230 \text{ Hz}}$$

$$\lambda = 0.53 \text{ m}$$

Statement: The wavelength is 0.53 m.

2. Given: F_T = 37 N;
μ = 0.03 g/m = 3×10^{-5} kg/m

Required: v

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

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

$$= \sqrt{\frac{37 \text{ N}}{3 \times 10^{-5} \text{ kg/m}}}$$

$$= \sqrt{\frac{37 \ \frac{\cancel{\text{kg}} \cdot \text{m}}{s^2}}{3 \times 10^{-5} \ \frac{\cancel{\text{kg}}}{\text{m}}}}$$

$$= 1.11 \times 10^3 \text{ m/s}$$

$$v = 1000 \text{ m/s}$$

Statement: The speed of sound along this string is 1000 m/s.

3. Given: $T = 1.20 \times 10^{-3}$ s; $v = 3.40 \times 10^2$ m/s

Required: λ

Analysis: $v = f\lambda$

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

$$\lambda = vT$$

Solution: $\lambda = vT$

$$= \left(3.40 \times 10^2 \ \frac{\text{m}}{\cancel{\text{s}}}\right)\left(1.20 \times 10^{-3} \ \cancel{\text{s}}\right)$$

$$\lambda = 0.408 \text{ m}$$

Statement: The wavelength is 0.408 m.

4. (a) P-waves:

Given: v = 8.0 km/s; $\Delta d = 2.4 \times 10^3$ km

Required: Δt

Analysis: $v = \frac{\Delta d}{\Delta t}$

$$\Delta t = v \Delta d$$

Solution: $\Delta t = \frac{\Delta d}{v}$

$$= \frac{2.4 \times 10^3 \ \cancel{\text{km}}}{8.0 \ \frac{\cancel{\text{km}}}{\text{s}}}$$

$$= \left(300 \ \cancel{\text{s}}\right)\left(\frac{1 \text{ min}}{60 \ \cancel{\text{s}}}\right)$$

$$\Delta t = 5 \text{ min}$$

Statement: The P-wave should arrive in 5 min.

S-waves:

Given: v = 4.5 km/s; $\Delta d = 2.4 \times 10^3$ km

Required: Δt

Analysis: $v = \frac{\Delta d}{\Delta t}$

$$\Delta t = v \Delta d$$

Solution: $\Delta t = \frac{\Delta d}{v}$

$$= \frac{2.4 \times 10^3 \ \cancel{\text{km}}}{4.5 \ \frac{\cancel{\text{km}}}{\text{s}}}$$

$$= \left(533.3 \ \cancel{\text{s}}\right)\left(\frac{1 \text{ min}}{60 \ \cancel{\text{s}}}\right)$$

$$\Delta t = 8.9 \text{ min}$$

Statement: The S-wave should arrive in 8.9 min.

(b) Transverse waves are called secondary waves because they arrive after the longitudinal wave.

(c) Answers may vary. Sample answer:
Observing these waves helps geophysicists analyze the structure of the Earth's interior. By collecting data from around the world, they can determine the location of a liquid core and the composition of the layers of Earth. The information is based on which waves arrive at various stations and how long it takes for them to get there.

5. The wavelength is halved. The speed stays the same because the tension and linear density remain the same. That means that when the value of f doubles in the equation $v = f\lambda$, the value of λ must be divided by two.

6. The speed is doubled. Given the equation $v = f\lambda$, when frequency is doubled, for the left side of the equation to equal the right side, the velocity should also be doubled.

7. You would have to multiply the tension by a factor of 4 to double the speed. Double the speed and see how it changes the tension (linear density remains constant):

$$v = 2\sqrt{\frac{F_T}{\mu}}$$
$$= \sqrt{4\frac{F_T}{\mu}}$$
$$v = \sqrt{\frac{(4F_T)}{\mu}}$$

So, when velocity is doubled, the tension should be multiplied by so that the left side of the equation equals the right side.

8. Start with the equation for force: $F_T = ma$.

Substitute for $a = \frac{v}{\Delta t}$: $F_T = m\frac{v}{\Delta t}$. Substitute for Δt knowing that the velocity is the length of the divided by the time:

$$F_T = m\frac{v}{\left(\frac{L}{v}\right)}$$
$$F_T = \frac{mv^2}{L}$$

Substitute in $\mu = \frac{m}{L}$, then rearrange to get the equation for wave speed on a string:

$$F_T = m\frac{v}{\left(\frac{L}{v}\right)}$$
$$F_T = v^2\mu$$
$$v^2 = \frac{F_T}{\mu}$$
$$v = \sqrt{\frac{F_T}{\mu}}$$

Section 8.5: Properties of Sound Waves

Research This: Using Ultrasound Technology in Medicine, page 392

A. This technology uses waves to break apart cancerous masses. The technology surgically removes previously inoperable tumours, such as brain tumours.

B. The ultrasound waves are at a specific frequency (about 23 kHz) that breaks up tumours without harming surrounding body tissue. The broken pieces are then easily removed through a hollow probe.

C. This technology is preferred over traditional surgery because it reduces blood loss. In addition, the tumour can be removed without causing serious damage to healthy surrounding tissue.

Tutorial 1 Practice, page 393

1. Given: $T = 32$ °C

Required: v

Analysis: $v = 331.4 \text{ m/s} + (0.606 \text{ m/s/°C})T$

Solution:

$$\begin{aligned} v &= 331.4 \text{ m/s} + (0.606 \text{ m/s/°C})T \\ &= 331.4 \text{ m/s} + \left(0.606 \frac{\text{m/s}}{\cancel{°\text{C}}}\right)(32 \cancel{°\text{C}}) \\ &= 331.4 \text{ m/s} + 19.4 \text{ m/s} \\ v &= 351 \text{ m/s} \end{aligned}$$

Statement: The speed of sound in 32 °C air is 351 m/s.

2. Given: $v = 333$ m/s

Required: T

Analysis: $v = 331.4 \text{ m/s} + (0.606 \text{ m/s/°C})T$

$$T = \frac{v - 331.4 \text{ m/s}}{0.606 \text{ m/s/°C}}$$

Solution:

$$\begin{aligned} T &= \frac{v - 331.4 \text{ m/s}}{0.606 \text{ m/s/°C}} \\ &= \frac{333 \text{ m/s} - 331.4 \text{ m/s}}{0.606 \text{ m/s/°C}} \\ &= \frac{1.6 \cancel{\text{m/s}}}{0.606 \frac{\cancel{\text{m/s}}}{°\text{C}}} \\ T &= 2.64 \text{ °C} \end{aligned}$$

Statement: The ambient temperature is 2.64 °C.

3. Given: $v = 350$ m/s

Required: T

Analysis: $v = 331.4 \text{ m/s} + (0.606 \text{ m/s/°C})T$

$$T = \frac{v - 331.4 \text{ m/s}}{0.606 \text{ m/s/°C}}$$

Solution:

$$\begin{aligned} T &= \frac{v - 331.4 \text{ m/s}}{0.606 \text{ m/s/°C}} \\ &= \frac{350 \text{ m/s} - 331.4 \text{ m/s}}{0.606 \text{ m/s/°C}} \\ &= \frac{18.6 \cancel{\text{m/s}}}{0.606 \frac{\cancel{\text{m/s}}}{°\text{C}}} \\ T &= 31 \text{ °C} \end{aligned}$$

Statement: The ambient temperature is 31 °C.

Tutorial 2 Practice, page 394

1. Given: $v_{\text{sound}} = 344$ m/s; $v_{\text{aircraft}} = 910$ km/h

Required: M

Analysis: $M = \frac{v_{\text{aircraft}}}{v_{\text{sound}}}$

Solution:

$$\begin{aligned} M &= \frac{v_{\text{aircraft}}}{v_{\text{sound}}} \\ &= \frac{910 \text{ km/h}}{344 \text{ m/s}} \\ &= \frac{910 \frac{\cancel{\text{km}}}{\cancel{\text{h}}}}{344 \frac{\cancel{\text{m}}}{\cancel{\text{s}}}}\left(\frac{1000 \cancel{\text{m}}}{1 \cancel{\text{km}}}\right)\left(\frac{1 \cancel{\text{h}}}{3600 \cancel{\text{s}}}\right) \\ M &= 0.73 \end{aligned}$$

Statement: The Mach number is 0.73.

2. Given: $v_{\text{sound}} = 320$ m/s; $M = 0.93$

Required: v_{airplane}

Analysis:

$$\begin{aligned} M &= \frac{v_{\text{airplane}}}{v_{\text{sound}}} \\ v_{\text{airplane}} &= Mv_{\text{sound}} \end{aligned}$$

Solution:

$$\begin{aligned} v_{\text{airplane}} &= Mv_{\text{sound}} \\ &= (0.93)(320 \text{ m/s}) \\ &= 297.6 \text{ m/s} \\ &= \left(297.6 \frac{\cancel{\text{m}}}{\cancel{\text{s}}}\right)\left(\frac{1 \cancel{\text{km}}}{1000 \cancel{\text{m}}}\right)\left(\frac{3600 \cancel{\text{s}}}{1 \cancel{\text{h}}}\right) \\ v_{\text{airplane}} &= 1100 \text{ km/h} \end{aligned}$$

Statement: The speed of the airplane is 1100 km/h.

3. Given: $v_{airplane}$ = 850 km/h; M = 0.81
Required: v_{sound}

Analysis: $M = \frac{v_{airplane}}{v_{sound}}$

$$v_{sound} = \frac{v_{airplane}}{M}$$

Solution:
$$\begin{aligned} v_{sound} &= \frac{v_{airplane}}{M} \\ &= \frac{850 \text{ km/h}}{0.81} \\ &= 1049 \text{ km/h} \\ v_{sound} &= 1.0 \times 10^3 \text{ km/h} \end{aligned}$$

Statement: The local speed of sound is 1.0×10^3 km/h, or 1000 km/h.

Mini Investigation: Testing Loudness, page 396

A. Answers may vary. Students' reports should include results of their measurements of the car stereo and include a warning about the hazards of listening to loud sounds for too long.

Section 8.5 Questions, page 397

1. (a) Cyanobacteria are also known as blue-green algae. It is important to control cyanobacteria because they are harmful if eaten.
(b) Cyanobacteria are traditionally controlled by chemicals such as copper sulphate. But using copper sulphate also kills any plants and animals in the water.
(c) The treatment proposes using low frequencies because such frequencies will immobilize the cyanobacteria. This is preferable to using high frequencies because high frequencies will break down the cell walls and spill the toxins into the water supply.
2. An aircraft flying at Mach 2 means that it is travelling at a speed equal to double the speed of the sound at that temperature.
3. Given: M = 0.83; T = 10 °C
Required: $v_{airplane}$
Analysis: $v_{sound} = 331.4 \text{ m/s} + (0.606 \text{ m/s/°C})T$;

$$M = \frac{v_{airplane}}{v_{sound}}$$

$$v_{airplane} = Mv_{sound}$$

Solution: Determine the local speed of sound:
$$\begin{aligned} v_{sound} &= 331.4 \text{ m/s} + (0.606 \text{ m/s/°C})T \\ &= 331.4 \text{ m/s} + \left(0.606 \frac{\text{m/s}}{\cancel{°C}}\right)(10 \cancel{°C}) \\ &= 331.4 \text{ m/s} + 6.06 \text{ m/s} \\ &= 337.46 \text{ m/s} \\ v_{sound} &= 337.5 \text{ m/s (two extra digits carried)} \end{aligned}$$

Determine the speed of the aircraft:
$$\begin{aligned} v_{airplane} &= Mv_{sound} \\ &= (0.83)(337.46 \text{ m/s}) \\ &= 280.09 \text{ m/s} \\ &= \left(280.09 \frac{\cancel{m}}{\cancel{s}}\right)\left(\frac{1 \text{ km}}{1000 \cancel{m}}\right)\left(\frac{3600 \cancel{s}}{1 \text{ h}}\right) \\ &= 1008 \text{ km/h} \\ v_{airplane} &= 1000 \text{ km/h} \end{aligned}$$

Statement: The speed of the airplane is 1000 km/h.
4. The speed of sound varies by temperature and density of the medium, both of which depend on the molecular structure of various particles.
5. (a) Sound intensity is a measure of energy per unit area due to a sound wave.
(b) Loudness is a measure of the sound intensity. It can also be defined as a human perception of sound energy.
(c) The decibel is the unit of measurement of sound level used to describe sound intensity.
6. Loudness is expressed in a logarithmic scale using decibels (dB). Decibels are a more convenient measurement unit than watts per square metre (W/m^2). The watt per square metre values for loudness can vary from 1.0×10^{-12} (the threshold of human hearing) to 1.0×10^{13} (an atomic bomb).
7. Sound intensity is a measure of energy flowing through the unit area due to a sound wave.
8. (a) Yes, the greater the loudness, the less time it is safe to listen.
(b) Answers may vary. Sample answer:
One website suggested listening to no more than 2 h of 100 dB sound a day. This corresponds to a volume of 8 on the scale given.

9. The power saw operates at 120 dB, which is 1.0 W/m^2. The sound level of the city street is 90 dB, which is 1.0×10^{-3} W/m^2.

$$\frac{1.0\text{ W/m}^2}{1.0\times10^{-3}\text{ W/m}^2} = \frac{1000}{1}$$

The ratio of the sound intensity the power saw compared to the city street is 1000:1.

10. Yes, the burglar's cough is louder than 1.0×10^{-7} W/m^2, or 50 dB, so it will be detected because it is more than 30 dB greater than the detection threshold of 1.0×10^{-10} W/m^2, or 20 dB.

11. (a) Barriers can be made of several materials. Barriers have been made of earth, wood, metal, concrete, and other materials.

(b) Sound barriers provide a physical barrier between highways and residential areas. The barriers absorb some of the sound waves, reflect some, and limit the sound waves that get by it to those that pass over the barrier.

(c) The barriers can be very effective at reducing residential noise. One website suggests that they can reduce traffic noise levels by 5 to 10 dB, cutting the loudness of the noise by as much as 50 %.

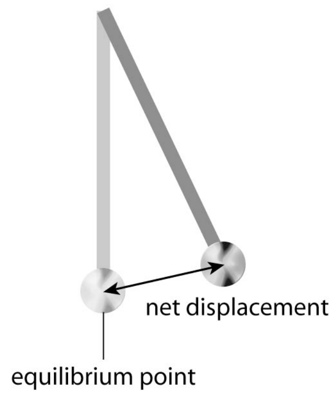
Chapter 8 Review, pages 408–413

Knowledge

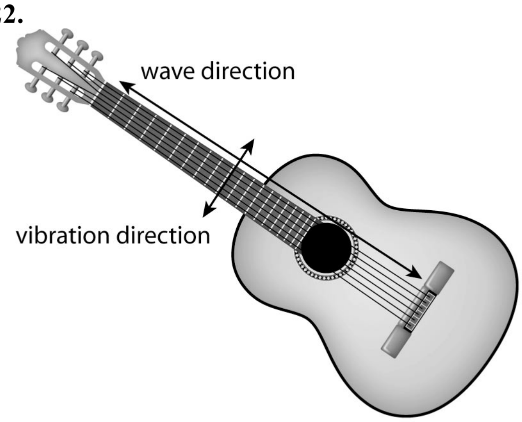
1. (b)
2. (c)
3. (d)
4. (a)
5. (c)
6. (b)
7. (c)
8. (a)
9. (b)
10. (d)
11. (d)
12. (c)
13. (a)
14. (a) (iv)
(b) (ii)
(c) (v)
(d) (iii)
(e) (i)
15. Answers may vary. Sample answer:
Three examples of waves that occur naturally are seismic waves, sound waves, and water waves.
16. As tension in the spring increases, the speed of the wave also increases.
17. The increase in pressure is caused by the collection of sound waves emitted by the aircraft that get closer and closer together as the aircraft approaches the speed of sound.
18. Answers may vary. Sample answer:
Noise pollution is the increase in loudness due to the sounds emitted by the surroundings. an example of noise pollution is the constant noise from cars on a nearby highway. This noise pollution can be reduced through construction of sound barriers along the highway or improvements to car engines.

Understanding

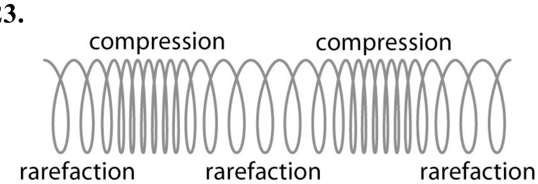
19.



20. Gases rely on translational molecular motion to transfer vibrations because gases have much lower density than liquids and solids and their gas molecules are much farther apart.
21. Vibrations are the cyclical motion of an object about an equilibrium point. Mechanical waves are the transfer of energy through a medium due to vibrations. Vibrations are the cause and waves are the effect.
22.



23.



24. Given: T = 0.280 s
Required: f

Analysis: $f = \frac{1}{T}$

Solution: $f = \frac{1}{T}$

$$= \frac{1}{0.280\ \text{s}}$$
$$f = 3.57\ \text{Hz}$$

Statement: The frequency of the pendulum is 3.57 Hz.

25. Given: f = 82 Hz
Required: T

Analysis: $f = \frac{1}{T}$

$$T = \frac{1}{f}$$

Solution: $T = \frac{1}{f}$

$$= \frac{1}{82\ \text{Hz}}$$
$$f = 0.012\ \text{s}$$

Statement: The period of the wave is 0.012 s.

26. Given: λ = 0.620 m; T = 0.300 s
Required: v

Analysis: $v = \frac{\lambda}{T}$

Solution: $v = \frac{\lambda}{T}$

$$= \frac{0.620\ \text{m}}{0.300\ \text{s}}$$
$$v = 2.07\ \text{m/s}$$

Statement: The speed of the wave is 2.07 m/s.

27. The amplitude of a longitudinal wave is defined as the maximum pressure it creates compared to the pressure of the non-disturbed medium.

28. (a) The wavelength is 5.4 cm and wave B is shifted 13.5 cm to the right of wave A.

$$\frac{13.5\ \cancel{\text{mm}}}{54\ \cancel{\text{mm}}} = 0.25$$

The phase shift is 0.25.

(b) The wavelength is 5.4 cm and wave B is shifted 13.5 cm to the left of wave A.

$$\frac{-13.5\ \cancel{\text{mm}}}{54\ \cancel{\text{mm}}} = -0.25$$

The phase shift is –0.25.

(c) The phase shift of B is half a wavelength. The phase shift is 0.5.

(d) The waves are in phase. The phase shift is 0.

29. Given: f = 0.40 Hz; λ = 7.0 m
Required: v
Analysis: $v = f\lambda$
Solution: $v = f\lambda$

$$= (0.40\ \text{Hz})(7.0\ \text{m})$$
$$v = 2.8\ \text{m/s}$$

Statement: The wave speed is 2.8 m/s.

30. Given: v = 343.2 m/s; T = 0.00226 s
Required: λ
Analysis: $v = f\lambda$

$$= \frac{\lambda}{T}$$
$$\lambda = vT$$

Solution: $\lambda = vT$

$$= \left(343.2\ \frac{\text{m}}{\cancel{\text{s}}}\right)(0.00226\ \cancel{\text{s}})$$
$$= 0.776\ \text{m}$$
$$\lambda = 77.6\ \text{cm}$$

Statement: The wavelength is 77.6 cm.

31. Given: m = 0.180 kg; L = 1.60 m
Required: μ

Analysis: $\mu = \frac{m}{L}$

Solution: $\mu = \frac{m}{L}$

$$= \frac{0.180\ \text{kg}}{1.60\ \text{m}}$$
$$\mu = 0.112\ \text{kg/m}$$

Statement: The linear density of the string is 0.112 kg/m.

32. Given: μ = 0.083 kg/m; L = 3.2 m
Required: m

Analysis: $\mu = \frac{m}{L}$

$$m = \mu L$$

Solution: $m = \mu L$

$$= \left(0.083\ \frac{\text{kg}}{\cancel{\text{m}}}\right)(3.2\ \cancel{\text{m}})$$
$$m = 0.27\ \text{kg}$$

Statement: The mass of the string is 0.27 kg.

33. Given: μ = 0.19 kg/m; F_T = 184 N
Required: v

Analysis: $v = \sqrt{\dfrac{F_T}{\mu}}$

Solution:
$$v = \sqrt{\frac{F_T}{\mu}}$$
$$= \sqrt{\frac{184\ \text{N}}{0.19\ \text{kg/m}}}$$
$$= \sqrt{\frac{184\ \dfrac{\cancel{\text{kg}}\bullet\text{m}}{s^2}}{0.19\ \dfrac{\cancel{\text{kg}}}{\text{m}}}}$$
$$v = 31\ \text{m/s}$$

Statement: The speed of a wave along the string is 31 m/s.

34. Given: F_T = 100.0 N; v = 40.0 m/s
Required: μ

Analysis: $v = \sqrt{\dfrac{F_T}{\mu}}$
$$v^2 = \frac{F_T}{\mu}$$
$$\mu = \frac{F_T}{v^2}$$

Solution:
$$\mu = \frac{F_T}{v^2}$$
$$= \frac{100.0\ \text{N}}{(40.0\ \text{m/s})^2}$$
$$= \frac{100.0\ \dfrac{\text{kg}\bullet\cancel{\text{m}}}{\cancel{s^2}}}{1600\ \dfrac{\text{m}^{\cancel{2}}}{\cancel{s^2}}}$$
$$\mu = 6.25\times10^{-2}\ \text{kg/m}$$

Statement: The linear density of the string is 6.25×10^{-2} kg/m, or 0.0625 kg/m.

35. Tightening the machine head increases the tension on the spring. As the tension increases, the wave speed increases. Likewise, loosening the machine head reduces the tension, which reduces the wave speed.

36. Waves generally travel faster in rigid media because the rigid intermolecular forces allow for a faster transfer of energy.

37. Given: T = 18 °C
Required: v

Analysis: $v = 331.4\ \text{m/s} + (0.606\ \text{m/s/°C})T$

Solution:
$$v = 331.4\ \text{m/s} + (0.606\ \text{m/s/°C})T$$
$$= 331.4\ \text{m/s} + \left(0.606\ \frac{\text{m/s}}{\cancel{°\text{C}}}\right)(18\ \cancel{°\text{C}})$$
$$= 331.4\ \text{m/s} + 10.9\ \text{m/s}$$
$$= 342.3\ \text{m/s}$$
$$v = 340\ \text{m/s}$$

Statement: The speed of sound in 18 °C air is 340 m/s.

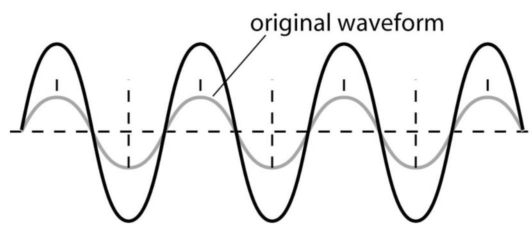
38. Given: v = 349 m/s
Required: T

Analysis: $v = 331.4\ \text{m/s} + (0.606\ \text{m/s/°C})T$
$$T = \frac{v - 331.4\ \text{m/s}}{0.606\ \text{m/s/°C}}$$

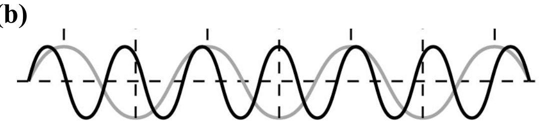
Solution:
$$T = \frac{v - 331.4\ \text{m/s}}{0.606\ \text{m/s/°C}}$$
$$= \frac{349\ \text{m/s} - 331.4\ \text{m/s}}{0.606\ \text{m/s/°C}}$$
$$= \frac{17.6\ \cancel{\text{m/s}}}{0.606\ \dfrac{\cancel{\text{m/s}}}{°\text{C}}}$$
$$T = 29.0\ °\text{C}$$

Statement: The ambient temperature is 29.0 °C.

39. (a)



(b)



40. Given: v_{sound} = 313 m/s; $v_{aircraft}$ = 907 km/h
Required: M

Analysis: $M = \dfrac{v_{aircraft}}{v_{sound}}$

Solution:
$$M = \frac{v_{aircraft}}{v_{sound}}$$
$$= \frac{907\ \text{km/h}}{313\ \text{m/s}}$$
$$= \frac{907\ \dfrac{\cancel{\text{km}}}{\cancel{\text{h}}}}{313\ \dfrac{\cancel{\text{m}}}{\cancel{s}}}\left(\frac{1000\ \cancel{\text{m}}}{1\ \cancel{\text{km}}}\right)\left(\frac{1\ \cancel{\text{h}}}{3600\ \cancel{s}}\right)$$
$$M = 0.805$$

Statement: The Mach number is 0.805.

41. Given: $v_{\text{sound}} = 300.0$ m/s; $M = 0.481$

Required: v_{airplane}

Analysis:
$$M = \frac{v_{\text{airplane}}}{v_{\text{sound}}}$$
$$v_{\text{airplane}} = Mv_{\text{sound}}$$

Solution:
$$\begin{aligned} v_{\text{airplane}} &= Mv_{\text{sound}} \\ &= (0.481)(300.0 \text{ m/s}) \\ &= 144.3 \text{ m/s} \\ &= \left(144.3 \frac{\cancel{\text{m}}}{\cancel{\text{s}}}\right)\left(\frac{1 \cancel{\text{k}}\text{m}}{1000 \cancel{\text{m}}}\right)\left(\frac{3600 \cancel{\text{s}}}{1 \cancel{\text{h}}}\right) \\ v_{\text{airplane}} &= 519 \text{ km/h} \end{aligned}$$

Statement: The speed of the airplane is 519 km/h.

42. Loudness is expressed in a logarithmic scale using decibels (dB). Decibels are a more convenient measurement unit than watts per square metre (W/m^2). The watt per square metre values for loudness can vary from 1.0×10^{-12} (the threshold of human hearing) to 1.0×10^{13} (an atomic bomb).

43. Answers may vary. Sample answer:
Aircraft were used to break the sound barrier. There are no forces of friction to slow down an aircraft unlike a car (which is dependent on wheels rolling on the ground).

Analysis and Application

44. Answers may vary. Sample answer:
I do not think you would hear any sound because there is no air in space for sound waves to travel through.

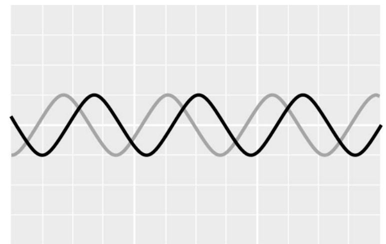
45. (a) Students should indicate the top of the wave on the right.

(b) Students should indicate the distance between the middle dotted line and either a crest or a trough.

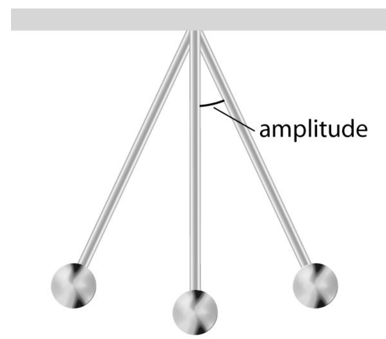
(c) Students should indicate the distance between a consecutive pair of waves.

(d) Students should indicate the bottom of the curve below the equilibrium, at the centre, as the trough.

46. Since each square represents 0.25 m, the new wave is shifted one square to the right:



47.



48. Given: $\lambda = 82$ cm $= 0.82$ m; $v = 540$ m/s

Required: f

Analysis:
$$v = f\lambda$$
$$f = \frac{v}{\lambda}$$

Solution:
$$\begin{aligned} f &= \frac{v}{\lambda} \\ &= \frac{540 \frac{\cancel{\text{m}}}{\text{s}}}{0.82 \cancel{\text{m}}} \\ f &= 6.6 \times 10^2 \text{ Hz} \end{aligned}$$

Statement: The frequency of the wave is 6.6×10^2 Hz, or 660 Hz.

49. Given: $v = 62$ m/s; $L = 0.60$ m; $F_T = 200$ N

Required: m

Analysis:
$$\begin{aligned} v &= \sqrt{\frac{F_T}{\mu}} \\ v^2 &= \frac{F_T}{\mu} \\ \mu &= \frac{F_T}{v^2} \\ \mu &= \frac{m}{L} \\ m &= \mu L \\ m &= \frac{F_T}{v^2} L \end{aligned}$$

Solution:

$$m = \frac{F_T}{v^2}L$$
$$= \frac{200\text{ N}}{(62\text{ m/s})^2}(0.60\text{ m})$$
$$= \frac{200\ \frac{\text{kg}\bullet\cancel{\text{m}}}{\cancel{\text{s}^2}}}{3844\ \frac{\cancel{\text{m}^2}}{\cancel{\text{s}^2}}}(0.60\ \cancel{\text{m}})$$
$$m = 3.1\times10^{-2}\text{ kg}$$

Statement: The mass of the string is 3.1×10^{-2} kg or 31 g.

50. Given: m = 0.220 kg; L = 4.30 m; v = 18.0 m/s

Required: F_T

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

$$v^2 = \frac{F_T}{\mu}$$
$$F_T = \mu v^2$$
$$F_T = \left(\frac{m}{L}\right)v^2$$

Solution: $F_T = \left(\frac{m}{L}\right)v^2$

$$= \frac{0.220\text{ kg}}{4.30\text{ m}}(18.0\text{ m/s})^2$$
$$= \frac{0.220\text{ kg}}{4.30\ \cancel{\text{m}}}\left(324.00\ \frac{\text{m}^{\cancel{2}}}{\text{s}^2}\right)$$
$$F_T = 16.6\text{ N}$$

Statement: The tension in the string is 16.6 N.

51. Given: f_E = 329.6 Hz; λ = 1.032 m; m = 180.0 g = 0.1800 kg; L = 32.0 cm = 0.320 m; f = 328.1 Hz

Required: ΔF_T

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

$$v^2 = \frac{F_T}{\mu}$$
$$F_T = \mu v^2$$
$$= \left(\frac{m}{L}\right)(f\lambda)^2$$
$$F_T = \frac{mf^2\lambda^2}{L}$$

Solution: Determine the current tension:

$$F_T = \frac{mf^2\lambda^2}{L}$$
$$= \frac{(0.1800\text{ kg})(328.1\text{ Hz})^2(1.032\text{ m})^2}{0.320\text{ m}}$$
$$F_T = 64\ 490\text{ N}$$

Determine the tension required for an E:

$$F_{TE} = \frac{mf_E{}^2\lambda^2}{L}$$
$$= \frac{(0.1800\text{ kg})(329.6\text{ Hz})^2(1.032\text{ m})^2}{0.320\text{ m}}$$
$$F_{TE} = 65\ 081\text{ N}$$

Determine the difference in tension:

$$\Delta F_T = F_{TE} - F_T$$
$$= 65\ 081\text{ N} - 64\ 490\text{ N}$$
$$\Delta F_T = 591\text{ N}$$

Statement: You need to increase the tension by 591 N.

52. Given: v = 1496 m/s

Required: T

Analysis: $v = 331.4\text{ m/s} + (0.606\text{ m/s/°C})T$

$$T = \frac{v - 331.4\text{ m/s}}{0.606\text{ m/s/°C}}$$

Solution: $T = \frac{v - 331.4\text{ m/s}}{0.606\text{ m/s/°C}}$

$$= \frac{1496\text{ m/s} - 331.4\text{ m/s}}{0.606\text{ m/s/°C}}$$
$$= \frac{1164.6\ \cancel{\text{m/s}}}{0.606\ \frac{\cancel{\text{m/s}}}{\text{°C}}}$$
$$T = 1922\text{ °C}$$

Statement: The air temperature would need to be 1922 °C.

53. Given: $v_{aircraft}$ = 48.3 km/h; M = 0.040

Required: T

Analysis: $v_{sound} = 331.4\text{ m/s} + (0.606\text{ m/s/°C})T$ **;**

$$M = \frac{v_{airplane}}{v_{sound}}$$
$$v_{sound} = \frac{v_{airplane}}{M}$$

Solution: Determine the speed of the sound:

$$v_{sound} = \frac{v_{airplane}}{M}$$

$$= \frac{48.3\ \frac{\text{km}}{\text{h}}}{0.040}\left(\frac{1000\text{ m}}{1\text{ km}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right)$$

$$= 335.4\text{ m/s (one extra digit carried)}$$

$$v_{sound} = 335\text{ m/s}$$

Determine the temperature:

$$v_{sound} = 331.4\text{ m/s} + (0.606\text{ m/s/°C})T$$

$$T = \frac{v_{sound} - 331.4\text{ m/s}}{0.606\text{ m/s/°C}}$$

$$T = \frac{335.4\ \text{m/s} - 331.4\ \text{m/s}}{0.606\ \frac{\text{m/s}}{\text{°C}}}$$

$$T = 6.6\text{ °C}$$

Statement: The air temperature is 6.6 °C.

54. Given: $T = -56.0$ °C; $M = 3.00$

Required: $v_{airplane}$

Analysis: $M = \frac{v_{airplane}}{v_{sound}}$

$$v_{airplane} = Mv_{sound}$$

Solution: Determine the local speed of sound:

$$v_{sound} = 331.4\text{ m/s} + (0.606\text{ m/s/°C})T$$

$$= 331.4\text{ m/s} + \left(0.606\ \frac{\text{m/s}}{\text{°C}}\right)(-56.0\text{ °C})$$

$$= 331.4\text{ m/s} - 33.936\text{ m/s}$$

$$= 297.46\text{ m/s}$$

$$v_{sound} = 297\text{ m/s}$$

Determine the speed of the aircraft:

$$v_{airplane} = Mv_{sound}$$

$$= (3.00)(297.46\text{ m/s})$$

$$= 892.38\text{ m/s}$$

$$= \left(892.38\ \frac{\text{m}}{\text{s}}\right)\left(\frac{1\text{ km}}{1000\text{ m}}\right)\left(\frac{3600\text{ s}}{1\text{ h}}\right)$$

$$= 3213.6\text{ km/h}$$

$$v_{airplane} = 3210\text{ km/h}$$

Statement: The speed of the airplane is 3210 km/h.

55. Answers may vary. Sample answer:
Without a medium, visual communication would be very useful. Some methods include writing, semaphore, and blinking lights in Morse code. Radio waves are a non-visual method of communication that work without a medium.

56. Answers may vary. Sample answer:
As propeller planes approach the speed of sound, the propellers lose effectiveness due to increased drag on the propeller blades. This requires that the propeller blades be travelling at a speed much greater than the speed of sound. The blades may also have difficulty with the change in pressure near the speed of sound.

57. Answers may vary. Sample answer:
Quartz clocks are still subject to temperature, but are more accurate than a mechanical watch.

58. Answers may vary. Students should have a journal of the sounds they hear during a day. Decibel levels will have to be estimated (unless sound meters are available) and may not be accurate, but the student should get an idea of the amount of sound they interact with on a daily basis.

59. Answers may vary. Sample answer:
When a musical instrument like a guitar or a piano is not tuned properly, the sound it makes will not be quite right. The tension of the strings needs to be adjusted to get the right sound.

Evaluation

60. (a) Given: $T_1 = 5.40$ °C; $T_2 = 26.4$ °C; $\Delta t = 0.5(0.250\text{ s}) = 0.125$ s

Required: Δd

Analysis: $\Delta d = d_2 - d_1$

Solution: Determine the speed of sound at T_1:

$$v_{sound1} = 331.4\text{ m/s} + (0.606\text{ m/s/°C})T_1$$

$$= 331.4\text{ m/s} + \left(0.606\ \frac{\text{m/s}}{\text{°C}}\right)(5.40\text{ °C})$$

$$= 331.4\text{ m/s} + 3.2724\text{ m/s}$$

$$= 334.67\text{ m/s}$$

$$v_{sound1} = 335\text{ m/s}$$

Determine the speed of sound at T_2:

$$v_{sound2} = 331.4\text{ m/s} + (0.606\text{ m/s/°C})T_2$$

$$= 331.4\text{ m/s} + \left(0.606\ \frac{\text{m/s}}{\text{°C}}\right)(26.4\text{ °C})$$

$$= 331.4\text{ m/s} + 15.998\text{ m/s}$$

$$= 347.40\text{ m/s}$$

$$v_{sound2} = 347\text{ m/s}$$

Determine the distance at v_{sound1}:

$$d_1 = v_{sound1}\Delta t$$
$$= (334.67 \text{ m/s})(0.125 \text{ s})$$
$$d_1 = 41.8 \text{ m}$$

Determine the distance at v_{sound2}:

$$d_2 = v_{sound1}\Delta t$$
$$= (347.40 \text{ m/s})(0.125 \text{ s})$$
$$d_2 = 43.4 \text{ m}$$

Statement: The range of distances from camera to subject is 41.8 m to 43.4 m.

(b) Answers may vary. Sample answer:
This difference in distance seems reasonable for a camera since the camera won't focus too differently for 40 m versus 50 m distances.

(c) Answers may vary. Sample answer:
No, I would want a much smaller range of error if measuring smaller distances.

Reflect on Your Learning

61. Answers may vary. Sample answer:
Sound is energy. I hadn't thought of sound in that way before.

62. Answers may vary. Sample answer:
I have a basic understanding now. I did not know that sound travels at different speeds in different media, and that there are different frequencies of sound.

63. Answers may vary. Sample answer:
I do not know if loud sound is really an issue. My hearing seems fine to me. OR I do not want to lose my hearing, so I think I will adjust my volume level when listening to my iPod.

Research

64. Answers may vary. Students' answers should indicate that sonograms allow doctors to examine soft tissue without having to operate on a patient. Sonograms are used to make images of muscles, tendons, breasts, liver, kidneys, brains, hearts, and other soft tissue in the body.

65. Answers may vary. Students' answers could include two of the following advantages of wave power: free, inexpensive, and renewable. Two disadvantages of wave power are the need for a consistent site and the variability of weather.

66. Answers may vary. Students' answers should indicated that ultrasound waves are used to determine the location of the stones. Then, high-energy sound waves are directed at the stones to break them into smaller, less invasive pieces that the body can flush out. Detailed descriptions of the physics behind this technology could be provided.

67. Answers may vary. Students' answers might include possible unaccredited flights that broke the sound barrier before Chuck Yeager; answers could include Thrust SSC setting the land speed record by breaking the sound barrier in 1997.

68. Answers may vary.

(a) Sample answer: Some animals that use infrasonic waves are whales, elephants, and giraffes.

(b) Students' answers should indicate that infrasonic waves allow animals to communicate over long distances especially when transmitted through a solid or liquid medium. For example, whales use infrasonic waves to communicate through hundreds of kilometres of ocean, and elephants can detect the waves transmitted through the ground. The early response by animals to natural disasters such as earthquakes and tsunamis may be because they can detect infrasonic waves that humans cannot detect.

69. Answers may vary. Students may include tornado detection, oil or gas leak detection, or arms testing detection.

70. Answers may vary. Historical string instruments include the harp, lute, lyre, rebab, sitar, erhu, and koto. The graphic organizer could be a table, t-chart, tree branch diagram, or other organizer.

71. (a) Descriptions should be similar to the following: Ultrasonic welding uses high-frequency vibrations to cause a tiny amount of melting at the joint of two materials.

(b) Answers may vary. Student answers should be similar to the following: Ultrasonic welding is used to manufacture a variety of medical and computer components, as well as plastic car parts and ordinary plastic containers that need to be airtight.

72. Answers may vary. Students' answers should include the following information:
The Wright brothers and others flew gliders before the first credited flight in 1903. One of the big hurdles to powered, manned flight was three axial control. The reports should compare the Wright Flyer I to other airplanes of this period. A comparison of the mechanical advantages and disadvantages between the Flyer I and other airplanes could be presented in a graphic organizer.

Chapter 9: Wave Interactions

Mini Investigation: Media Changes, page 415

A. In each situation, the transmitted wave keeps the orientation of the original wave while the reflected wave has the opposite orientation.
B. The sum of the two new amplitudes (of the reflected wave and the transmitted wave) equals the amplitude of the original wave.

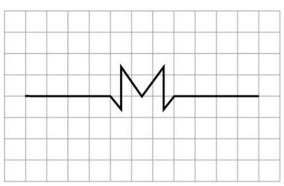
Section 9.1: Interference of Waves

Mini Investigation: Demonstrating Interference with Springs, page 417

A. When a single pulse was sent down the Slinky, the tab reached an amplitude that equalled the amplitude of the pulse.
B. When two positive pulses were sent down the Slinky from opposite ends, the tab reached an amplitude that equalled the sum of the amplitudes of the pulse.
C. When a positive pulse and a negative pulse were sent down the Slinky, the tab did not move.

Tutorial 1 Practice, page 419

1.



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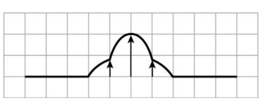
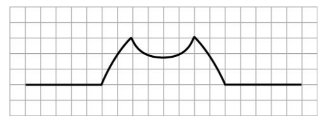
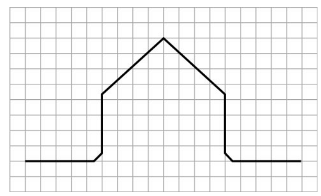


Section 9.1 Questions, page 419

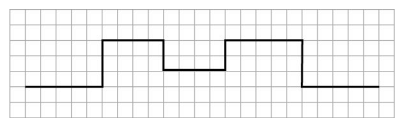
1. (a) When waves in phase combine, then the resulting amplitude is the sum of the two original amplitudes.
(b) When waves out of phase combine, they form a wave with an amplitude less than at least one of the initial waves.
2. (a)



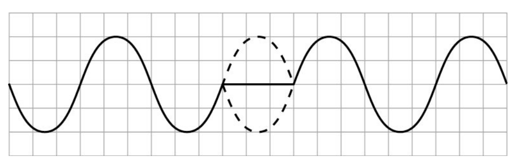
(b)



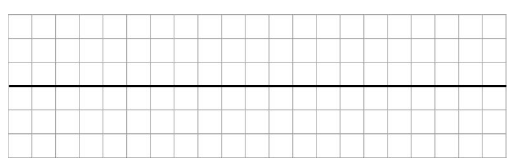
(c)



3. (a) Answers may vary. Sample answer:
The two waves are out of phase by half a wavelength, so they would cancel one another.
(b) Since every point on the wave coming from the left has the same amplitude but in the opposite direction of its equivalent point on the wave coming from the right, the interference will result in no amplitude.



(c) Eventually, the waves will completely cancel each other out, leaving just the equilibrium point.



Section 9.2: Waves at Media Boundaries

Tutorial 1 Practice, page 425

1. (a) Given: $f = 2(200.0\text{ Hz}) = 400.0\text{ Hz}$; $v = 350\text{ m/s}$; $n = 1$; free and fixed ends

Required: L_1

Analysis: $L_n = \dfrac{2n-1}{4}\lambda$

Solution:

$$L_n = \frac{2n-1}{4}\lambda$$

$$L_1 = \frac{1}{4}\left(\frac{v}{f}\right) = \frac{1}{4}\left(\frac{350\text{ m/s}}{400\text{ Hz}}\right)$$

$$L_1 = 0.22\text{ m}$$

Statement: The length of rope is 0.22 m if the frequency is double.

(b) Given: $f = 200.0\text{ Hz}$; $v = 350\text{ m/s}$; $n = 3$; free and fixed ends

Required: L_3

Analysis: $L_n = \dfrac{2n-1}{4}\lambda$

Solution:

$$L_n = \frac{2n-1}{4}\lambda$$

$$L_3 = \frac{5}{4}\left(\frac{v}{f}\right) = \frac{5}{4}\left(\frac{350\text{ m/s}}{200\text{ Hz}}\right)$$

$$L_3 = 2.2\text{ m}$$

Statement: The length of the string is 2.2 m.

(c) Given: $f = 200.0\text{ Hz}$; $v = 200\text{ m/s}$; $n = 1$; free and fixed ends

Required: L_1

Analysis: $L_n = \dfrac{2n-1}{4}\lambda$

Solution: $L_n = \dfrac{2n-1}{4}\lambda$

$$L_1 = \frac{1}{4}\left(\frac{v}{f}\right) = \frac{1}{4}\left(\frac{200\text{ m/s}}{200\text{ Hz}}\right)$$

$$L_1 = 0.25\text{ m}$$

Statement: The length of rope is 0.25 m.

2. (a) Given: $L_6 = 0.65\text{ m}$; $v_6 = 206\text{ m/s}$; $n = 6$; $f_6 = 950\text{ Hz}$; $v = 150\text{ m/s}$; two fixed ends

Required: f

Analysis: $\lambda = \dfrac{v}{f}$

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

Solution: Determine the wavelength:

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

$$\lambda = \frac{v_6}{f_6} = \frac{206\text{ m/s}}{950\text{ Hz}}$$

$\lambda = 0.2168\text{ m}$ (two extra digits carried)

Determine the frequency:

$$f = \frac{v}{\lambda} = \frac{150\text{ m/s}}{0.2168\text{ m}}$$

$$f = 690\text{ Hz}$$

Statement: The frequency is 690 Hz.

(b) Given: $L_6 = 0.65\text{ m}$; $v_6 = 206\text{ m/s}$; $n = 6$; $f_6 = 950\text{ Hz}$; $v = 350\text{ m/s}$; two fixed ends

Required: f

Analysis: $\lambda = \dfrac{v}{f}$

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

Solution: Determine the wavelength:

$$\lambda = \frac{v_6}{f_6} = \frac{206\text{ m/s}}{950\text{ Hz}}$$

$\lambda = 0.2168\text{ m}$ (two extra digits carried)

Determine the frequency:

$$f = \frac{v}{\lambda} = \frac{350\text{ m/s}}{0.2168\text{ m}}$$

$$f = 1600\text{ Hz}$$

Statement: The frequency is 1600 Hz.

3. Given: L = 1 m; f_4 = 44 kHz = 44 000 Hz; two fixed ends
Required: f_0; f_1; f_2; f_3

Analysis:
$$\lambda = \frac{v}{f_4}$$
$$L = \frac{n\lambda}{2}$$
$$\frac{2L}{n} = \lambda$$
$$= \frac{v}{f}$$
$$f = \frac{vn}{2L}$$

Solution: Determine the speed from the fourth overtone:
$$\lambda = \frac{v}{f_4}$$
$$v = \lambda f_4$$
$$= \left(\frac{2L}{n}\right) f_4$$
$$= \left(\frac{2(1\text{ m})}{5}\right)(44\ 000\text{ Hz})$$
$$v = 17\ 600\text{ m/s (one extra digit carried)}$$

Determine the frequency of the first harmonic:
$$L = \frac{n\lambda}{2}$$
$$f = \frac{vn}{2L}$$
$$f_0 = \frac{(17\ 600\ \cancel{\text{m}}/\text{s})(1)}{2(1\ \cancel{\text{m}})}$$
$$f_0 = 8800\text{ Hz}$$

Determine the frequency of the second harmonic:
$$f = \frac{vn}{2L}$$
$$f_1 = \frac{(17\ 600\ \cancel{\text{m}}/\text{s})(2)}{2(1\ \cancel{\text{m}})}$$
$$f_1 = 17\ 600\text{ Hz}$$

Determine the frequency of the third harmonic:
$$f = \frac{vn}{2L}$$
$$f_2 = \frac{(17\ 600\ \cancel{\text{m}}/\text{s})(3)}{2(1\ \cancel{\text{m}})}$$
$$f_2 = 26\ 400\text{ Hz}$$

Determine the frequency of the fourth harmonic:
$$f = \frac{vn}{2L}$$
$$f_3 = \frac{(17\ 600\ \cancel{\text{m}}/\text{s})(4)}{2(1\ \cancel{\text{m}})}$$
$$f_3 = 35\ 200\text{ Hz}$$

Statement: The first and second harmonics are within the range of human hearing (20 Hz to 20 kHz).

Mini Investigation: Creating Standing Waves, page 426

A. There is a standing wave with only one node at the fixed end of the rope.
B. Once the first harmonic was achieved, I had to move the rope up and down at a constant amplitude and speed.
C. Answers may vary. Students' predictions should be based on what they know about the standing wave machine and what they can calculate using the material they just learned.
D. Answers may vary. Students should explain any differences between the prediction from C and the actual frequency for f_0.

Section 9.2 Questions, page 426

1. (a) When two or more waves interact and the resulting wave appears to be stationary, this wave is called a standing wave.
(b) The fundamental frequency is the lowest frequency that can produce a standing wave in a given medium.
(c) A node is the point in a standing wave at which the particles are at rest.
(d) Harmonics are the whole-number multiples of the fundamental frequency.
2. An example of a wave that encounters a media boundary is being in a cave and having my speech echo within the cave.
(a) The reflected wave will have the same amplitude while the amplitude of the transmitted wave will decrease.
(b) Yes; Answers may vary. Sample answer: When there is a change in medium, the wave splits into a reflected wave and a transmitted wave. The sum of the amplitudes of these two waves is the same as the original, meaning both of the new amplitudes will be smaller than the original wave's amplitude. Hence, the answer in part (a) is supported by the change in medium.

3. Answers may vary. Two examples of free-end reflection are whips and shaking a dangling cat toy. Examples of fixed-end reflection include string musical instruments such as violins, guitars, and harps.

4. The length of the medium must be a whole-number multiple of the first harmonic.

5. Given: L_1 = 2.4 m; v = 450 m/s; n = 1; two fixed ends

Required: f

Analysis: $L_1 = \dfrac{n\lambda}{2}$

$\lambda = \dfrac{v}{f}$

$f = \dfrac{v}{\lambda}$

Solution: Determine the wavelength:

$$L_1 = \frac{n\lambda}{2}$$
$$\lambda = \frac{2L_1}{n} = \frac{2(2.4\ \text{m})}{1}$$
$$\lambda = 4.8\ \text{m}$$

Determine the frequency:

$$f = \frac{v}{\lambda} = \frac{450\ \text{m/s}}{4.8\ \text{m}}$$
$$f = 94\ \text{Hz}$$

Statement: The frequency of the wave that would produce the first harmonic is 94 Hz.

6. Given: L_2 = 1.2 m; T = 20 °C; n = 2; two open ends

Required: f_1

Analysis: $L_2 = \dfrac{n\lambda}{2}$; $v = 331.4\ \text{m/s} + (0.606\ \text{m/s/°C})T$;

$\lambda = \dfrac{v}{f}$

$f = \dfrac{v}{\lambda}$

Solution: Determine the wavelength:

$$L_2 = \frac{n\lambda}{2}$$
$$\lambda = \frac{2L_1}{n} = \frac{2(1.2\ \text{m})}{2}$$
$$\lambda = 1.2\ \text{m}$$

Determine the speed of sound in the air:

$$v = 331.4\ \text{m/s} + (0.606\ \text{m/s/°C})T$$
$$= 331.4\ \text{m/s} + \left(0.606\ \frac{\text{m/s}}{\cancel{\text{°C}}}\right)(20\ \cancel{\text{°C}})$$
$$v = 343.5\ \text{m/s}$$

Determine the frequency:

$$f = \frac{v}{\lambda} = \frac{343.5\ \text{m/s}}{1.2\ \text{m}}$$
$$f = 290\ \text{Hz}$$

Statement: The frequency of the second harmonic is 290 Hz.

7. Given: T = 25 °C; f = 340 Hz; n = 3; fixed and open ends

Required: L

Analysis: $v = 331.4\ \text{m/s} + (0.606\ \text{m/s/°C})T$; $\lambda = \dfrac{v}{f}$;

$L_n = \dfrac{2n-1}{4}\lambda$

Solution: Determine the speed of sound in the air:

$$v = 331.4\ \text{m/s} + (0.606\ \text{m/s/°C})T$$
$$= 331.4\ \text{m/s} + \left(0.606\ \frac{\text{m/s}}{\cancel{\text{°C}}}\right)(25\ \cancel{\text{°C}})$$
$$v = 346.6\ \text{m/s}$$

Determine the wavelength:

$$\lambda = \frac{v}{f} = \frac{346.6\ \text{m/s}}{340\ \text{Hz}}$$
$$\lambda = 1.019\ \text{m (two extra digits carried)}$$

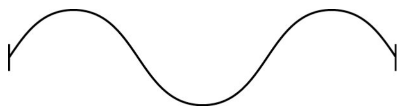
Determine the length:

$$L_n = \frac{2n-1}{4}\lambda$$
$$L_3 = \frac{5}{4}\lambda = \frac{5}{4}(1.019\ \text{m})$$
$$L_3 = 1.3\ \text{m}$$

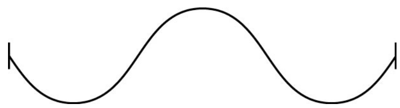
Statement: The length of the air column is 1.3 m.

8. Answers may vary. Sample answer using third harmonic:

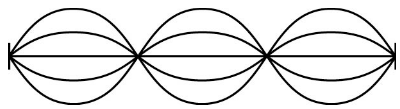
(a)



(b)



(c)



Section 9.3: Beats

Mini Investigation: Wave Beat Demonstration, page 428

A. The beat pattern emerges when two waves of similar but slightly different frequencies overlap. One wave is the graph the program is trying to draw and the other wave is the location of the pixels of the computer screen.

Mini Investigation: Creating Beats, page 428

Answers may vary. Sample answers:

A. I think the waveform produced in Step 5 is a beat because it is the result of the interference of two sound waves.

B. No, I do not think the beat pattern would change if I tapped the tuning forks at different times because they would still emit the same sound waves with the same amplitude and frequency.

Research This: Humming Fish, page 429

A. The frequency of the males' humming is in the range of 90 Hz to 100 Hz.

B. Answers may vary. Sample answer:
I thought the humming sounded like a distant airplane.

C. The females are attracted to humming with a frequency of 100 Hz. So, when they encounter an acoustic beat of two or more males humming, the females' brains can isolate the overlapping sound waves and swim to the male with the better frequency.

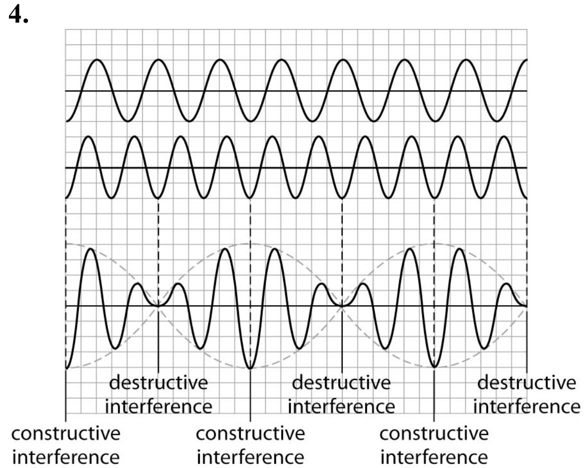
Section 9.3 Questions, page 429

1. Answers may vary. Sample answer:
When waves in the same medium interact, they interfere with each other according to the principle of superposition. At times, the waves are in phase, and constructive interference occurs. At other times, waves are out of phase, and destructive interference occurs. These changes in phase produce a change in loudness, which is the beat.

2. You should loosen the string. To tune the guitar correctly, the beats should not be audible which means the beat frequency should be zero.

3. The sound waves produced by two engines probably have similar amplitudes but different frequencies. As the sound waves move in and out of phase, a change in loudness, or acoustic beat, arises.

4.



Section 9.4: Damping and Resonance

Section 9.4 Questions, page 432

1. (a) Damping describes the reduction in a wave's amplitude, either because of energy absorption or destructive interference.
(b) The resonant frequency is the frequency at which a medium vibrates most easily.
(c) Resonance is the condition in which the frequency of a wave equals the resonant frequency of the wave's medium.
2. (a) The two causes of damping are energy absorption by a medium and destructive interference between two or more waves.
(b) Damping can be caused by a medium absorbing wave energy, causing the amplitude of the wave to get smaller. Damping can also occur when destructive interference from superimposed waveforms results in a wave whose resultant amplitude is smaller.
3. The motion of a mass–spring system eventually stops because air resistance and friction in the system reduces the wave energy. This damping reduces the amplitude to zero.
4. Answers may vary. Sample answer:
The purpose of shock absorbers is to quickly dampen any up-and-down motion and keep the car tires from lifting off the road. Shock absorbers work in a similar way to pistons. As the shocks are compressed, energy is absorbed and thermal energy is generated in the compressed air and fluid inside them. This thermal energy can be released as exhaust.
5. Standing waves are a result of an interference pattern of a series of reflected waves. Standing waves occur at one of a medium's harmonics, and since the resonant frequency is one of the medium's harmonics, standing waves are an example of resonance.
6. Answers may vary. One example of damping is bungee jumping where the person hanging by a bungee rope bounces for a while but eventually comes to a stop due to damping. Another example of damping is an echo produced in open air that dies down after a few reflections.
7. Answers may vary. Sample answer:
(a) The Millennium Bridge in London, England was built in 2000. It was quickly renamed the "Wobbly Bridge" as engineers had failed to take into account that pedestrians tended to walk in step. This social coherence created an input frequency acting on the bridge which then started to oscillate. It was quickly closed down until dampening systems were put in place. It reopened again in 2002.
When a tuning fork is struck and brought in contact with the strings inside a piano, the piano starts playing at a resonant frequency.
(b) In the case of the bridge, there is damping due to energy lost as a result of air resistance and the fixed ends of the bridge. In the case of the tuning fork, there is damping due to energy lost as a result of air resistance and the tuning fork.
8. (a) Yes, resonance occurs at one of the harmonics, so the amplitude is maximized.
(b) Yes, I would expect multiple resonant frequencies because there are multiple harmonics.

Section 9.5: The Doppler Effect

Tutorial 1 Practice, page 435

1. Given: v_{source} = 20.0 m/s; f_0 = 1.0 kHz; $v_{detector}$ = 0 m/s; v_{sound} = 330 m/s

Required: f_{obs}

Analysis:

$$f_{obs} = \left(\frac{v_{sound} + v_{detector}}{v_{sound} + v_{source}}\right) f_0$$

Solution:

$$\begin{aligned} f_{obs} &= \left(\frac{v_{sound} + v_{detector}}{v_{sound} + v_{source}}\right) f_0 \\ &= \left(\frac{330 \text{ m/s} + 0 \text{ m/s}}{330 \text{ m/s} + (-20.0 \text{ m/s})}\right)(1.0 \text{ kHz}) \\ &= \left(\frac{330 \cancel{\text{m/s}}}{310 \cancel{\text{m/s}}}\right)(1.0 \text{ kHz}) \\ &= 1100 \text{ Hz} \\ f_{obs} &= 1.1 \text{ kHz} \end{aligned}$$

Statement: The detected frequency of the approaching police car is 1100 Hz, or 1.1 kHz.

2. Given: f_{obs} = 900.0 Hz; $v_{detector}$ = 0 m/s; f_0 = 950.0 Hz; v_{sound} = 335 m/s

Required: v_{source}

Analysis:

$$f_{obs} = \left(\frac{v_{sound} + v_{detector}}{v_{sound} + v_{source}}\right) f_0$$

$$v_{sound} + v_{source} = \frac{f_0}{f_{obs}}(v_{sound} + v_{detector})$$

$$v_{source} = \frac{f_0}{f_{obs}}(v_{sound} + v_{detector}) - v_{sound}$$

Solution:

$$\begin{aligned} v_{source} &= \frac{f_0}{f_{obs}}(v_{sound} + v_{observer}) - v_{sound} \\ &= \frac{950.0 \text{ Hz}}{900.0 \text{ Hz}}(335 \text{ m/s} + 0 \text{ m/s}) - (335 \text{ m/s}) \\ &= \frac{95 \cancel{\text{Hz}}}{90 \cancel{\text{Hz}}}(335 \text{ m/s}) - 335 \text{ m/s} \\ v_{source} &= 18.6 \text{ m/s} \end{aligned}$$

Statement: The speed of the ambulance is 18.6 m/s.

Section 9.5 Questions, page 435

1. (a) The Doppler effect describes the changing frequency of sound as the source is in motion relative to an observer.

(b) Answers may vary. Sample answer:
Two examples of the Doppler effect are the noise of a jet at an air show and the sound of a racecar to someone near the track.

2. A sound wave has a higher frequency when the source is approaching a stationary observer because the sound waves are compressed as the source gets closer to the observer. Compressed sound waves mean a higher frequency.

3. Given: f_0 = 300.0 Hz; T = 15 °C; $v_{detector}$ = 0 m/s; v_{source} = 25 m/s

Required: f_{obs}

Analysis: $v_{sound} = 331.4 \text{ m/s} + (0.606 \text{ m/s/°C})T$;

$$f_{obs} = \left(\frac{v_{sound} + v_{detector}}{v_{sound} + v_{source}}\right) f_0$$

Solution: Determine the speed of sound at 15 °C:

$$\begin{aligned} v_{sound} &= 331.4 \text{ m/s} + (0.606 \text{ m/s/°C})T \\ &= 331.4 \text{ m/s} + \left(0.606 \frac{\text{m/s}}{\cancel{°\text{C}}}\right)(15 \cancel{°\text{C}}) \\ v_{sound} &= 340.5 \text{ m/s} \end{aligned}$$

Determine the frequency detected by the observer:

$$\begin{aligned} f_{obs} &= \left(\frac{v_{sound} + v_{detector}}{v_{sound} + v_{source}}\right) f_0 \\ &= \left(\frac{340.5 \text{ m/s} + 0 \text{ m/s}}{340.5 \text{ m/s} + (-25 \text{ m/s})}\right)(300.0 \text{ Hz}) \\ &= \left(\frac{340.5 \cancel{\text{m/s}}}{315.5 \cancel{\text{m/s}}}\right)(300.0 \text{ Hz}) \\ f_{obs} &= 320 \text{ Hz} \end{aligned}$$

Statement: The detected frequency of the object is 320 Hz.

4. Given: f_0 = 850 Hz; Δf = 58 Hz; $v_{detector}$ = 0 m/s; v_{sound} = 345 m/s

Required: v_{source}

Analysis: $f_{obs} = f_0 + \Delta f$;

$$f_{obs} = \left(\frac{v_{sound} + v_{detector}}{v_{sound} + v_{source}}\right) f_0$$

$$v_{sound} + v_{source} = \frac{f_0}{f_{obs}}(v_{sound} + v_{detector})$$

$$v_{source} = \frac{f_0}{f_{obs}}(v_{sound} + v_{detector}) - v_{sound}$$

Solution: Determine the observed frequency:

$$\begin{aligned} f_{obs} &= f_0 + \Delta f \\ &= 850 \text{ Hz} + 58 \text{ Hz} \\ f_{obs} &= 908 \text{ Hz} \end{aligned}$$

Determine the speed of the fire truck:

$$v_{source} = \frac{f_0}{f_{obs}}\left(v_{sound} + v_{detector}\right) - v_{sound}$$

$$= \frac{850\ \cancel{Hz}}{908\ \cancel{Hz}}\left(345\text{ m/s} + 0\text{ m/s}\right) - \left(345\text{ m/s}\right)$$

$$v_{source} = -22\text{ m/s}$$

Statement: The speed of the fire truck is 22 m/s.

5. Given: v_{source} = 0 m/s; f_0 = 440.0 Hz; $v_{detector}$ = 90 km/h; T = 0 °C

Required: f_{obs}

Analysis:

$$f_{obs} = \left(\frac{v_{sound} + v_{detector}}{v_{sound} + v_{source}}\right)f_0$$

Solution: Since the temperature is 0 °C, the speed of sound is 331.4 m/s.

Convert v_{source} to metres per second:

$$v_{source} = 90\text{ km/h}$$

$$= 90\ \frac{\cancel{km}}{\cancel{h}}\left(\frac{1000\text{ m}}{1\ \cancel{km}}\right)\left(\frac{1\ \cancel{h}}{60\ \cancel{min}}\right)\left(\frac{1\ \cancel{min}}{60\text{ s}}\right)$$

$$v_{source} = 25\text{ m/s}$$

Determine the observed frequency of the horn as I approach the observer:

$$f_{obs} = \left(\frac{v_{sound} + v_{detector}}{v_{sound} + v_{source}}\right)f_0$$

$$= \left(\frac{331.4\text{ m/s} + 0\text{ m/s}}{331.4\text{ m/s} + \left(-25\text{ m/s}\right)}\right)\left(440\text{ Hz}\right)$$

$$= \left(\frac{331.4\ \cancel{m/s}}{306.4\ \cancel{m/s}}\right)\left(440\text{ Hz}\right)$$

$$f_{obs} = 480\text{ Hz}$$

As I pass the observer, the person will detect the exact frequency of the horn.

Statement: The person will detect a frequency of 480 Hz as I approach, and a frequency of 440 Hz as I pass.

6. Given: $v_{detector}$ = 0 m/s; f_{obs} = 560 Hz; v_{sound} = 345 m/s; f_0 = 480 Hz

Required: v_{source}

Analysis:

$$f_{obs} = \left(\frac{v_{sound} + v_{detector}}{v_{sound} + v_{source}}\right)f_0$$

$$v_{sound} + v_{source} = \frac{f_0}{f_{obs}}\left(v_{sound} + v_{detector}\right)$$

$$v_{source} = \frac{f_0}{f_{obs}}\left(v_{sound} + v_{detector}\right) - v_{sound}$$

Solution:

$$v_{source} = \frac{f_0}{f_{obs}}\left(v_{sound} + v_{observer}\right) - v_{sound}$$

$$= \frac{560\text{ Hz}}{480\text{ Hz}}\left(345\text{ m/s} + 0\text{ m/s}\right) - \left(345\text{ m/s}\right)$$

$$= \frac{56\ \cancel{Hz}}{48\ \cancel{Hz}}\left(345\text{ m/s}\right) - 345\text{ m/s}$$

$$v_{source} = 58\text{ m/s}$$

Statement: The speed of the source is 58 m/s.

7. The frequency reduces. The effect is not instantaneous as it depends on the speed of the source and how far the source is from the observer.

Chapter 9 Review, pages 442–447

Knowledge

1. (b)
2. (c)
3. (b)
4. (d)
5. (b)
6. (d)
7. (d)
8. (b)
9. (a)
10. (c)
11. (a)
12. (c)
13. (b)
14. (b)
15. (d)
16. False. Interference *does not* leave a wave permanently altered.
17. False. Halfway between two identical in-phase sound sources, one would find an *antinode*.
18. True
19. True
20. False. A pipe that is closed at one end resonates at a *lower* frequency than an identical pipe that is open at both ends.
21. False. If you pluck a violin string several times in a row and determine that the frequency remains the same, you have demonstrated the violin string's *resonant frequency*.
22. False. When you push a child's swing until it starts swinging on its own, you have found the swing's *resonant frequency*.
23. False. Each harmonic of a guitar string has a *frequency that is a multiple of the fundamental* frequency.
24. True
25. True
26. True
27. False. If a cello instructor and her student play the same string on their cellos at the same time, *no* beats should be heard.
28. False. An antinode is the *location at which the wave particles move at greatest speed*.
29. True
30. True
31. (a) (iii)
(b) (iv)
(c) (v)
(d) (i)
(e) (ii)
32. (a) A guitar is a fixed-end instrument.
(b) A flute is a free-end instrument.
(c) An organ pipe is a free-end instrument.
(d) A piano is a fixed-end instrument.
33. Air temperature affects the tuning of an instrument that uses air columns because the speed of a sound wave is affected by the air temperature. At different temperatures, frequencies will be different because the speed of sound is different.
34. The wave will not be a standing wave (it will not have nodes and antinodes).
35. By the principle of superposition, the overlapping waves create areas of constructive and destructive interference, which create the beat.
36. No. The Doppler effect will not be produced when the speed of the source is so much slower than the speed of the sound.

Understanding

37. The transmitted wave keeps the orientation of the original wave, while the reflected wave has the opposite orientation.
38. (a) Given: L = 60.0 cm = 0.600 m; T = 15.0 °C; free and fixed ends
Required: f_1; f_2; f_3
Analysis: $v = 331.4 \text{ m/s} + \left(0.606 \text{ m/s/°C}\right)T$;

$$L_n = \frac{2n-1}{4}\lambda$$
$$= \frac{2n-1}{4}\left(\frac{v}{f_n}\right)$$
$$f_n = \frac{2n-1}{4}\left(\frac{v}{L_n}\right)$$

Solution: Determine the speed of sound at 15 °C:

$$v = 331.4 \text{ m/s} + \left(0.606 \text{ m/s/°C}\right)T$$
$$= 331.4 \text{ m/s} + \left(0.606 \ \frac{\text{m/s}}{\cancel{°C}}\right)\left(15 \ \cancel{°C}\right)$$
$$v = 340.5 \text{ m/s}$$

Determine the first three harmonics:

$$f_n = \frac{2n-1}{4}\left(\frac{v}{L_n}\right)$$
$$f_1 = \frac{1}{4}\left(\frac{340.5 \text{ m/s}}{0.600 \text{ m}}\right)$$
$$f_1 = 142 \text{ Hz}$$

$$f_n = \frac{2n-1}{4}\left(\frac{v}{L_n}\right)$$
$$f_2 = \frac{3}{4}\left(\frac{340.5 \text{ m/s}}{0.600 \text{ m}}\right)$$
$$f_2 = 426 \text{ Hz}$$

$$f_n = \frac{2n-1}{4}\left(\frac{v}{L_n}\right)$$
$$f_3 = \frac{5}{4}\left(\frac{340.5 \text{ m/s}}{0.600 \text{ m}}\right)$$
$$f_3 = 709 \text{ Hz}$$

Statement: The first three harmonic frequencies are 142 Hz, 426 Hz, and 709 Hz.

(b) Given: L = 60.0 cm = 0.600 m; T = 30.0 °C; free and fixed ends

Required: f_1; f_2; f_3

Analysis: $v = 331.4 \text{ m/s} + (0.606 \text{ m/s/°C})T$;

$$L_n = \frac{2n-1}{4}\lambda$$
$$= \frac{2n-1}{4}\left(\frac{v}{f_n}\right)$$
$$f_n = \frac{2n-1}{4}\left(\frac{v}{L_n}\right)$$

Solution: Determine the speed of sound at 30 °C:

$$v = 331.4 \text{ m/s} + (0.606 \text{ m/s/°C})T$$
$$= 331.4 \text{ m/s} + \left(0.606 \ \frac{\text{m/s}}{\cancel{°\text{C}}}\right)(30 \ \cancel{°\text{C}})$$
$$v = 349.6 \text{ m/s}$$

Determine the first three harmonics:

$$f_n = \frac{2n-1}{4}\left(\frac{v}{L_n}\right)$$
$$f_1 = \frac{1}{4}\left(\frac{349.6 \text{ m/s}}{0.600 \text{ m}}\right)$$
$$f_1 = 146 \text{ Hz}$$

$$f_n = \frac{2n-1}{4}\left(\frac{v}{L_n}\right)$$
$$f_2 = \frac{3}{4}\left(\frac{349.6 \text{ m/s}}{0.600 \text{ m}}\right)$$
$$f_2 = 437 \text{ Hz}$$

$$f_n = \frac{2n-1}{4}\left(\frac{v}{L_n}\right)$$
$$f_3 = \frac{5}{4}\left(\frac{349.6 \text{ m/s}}{0.600 \text{ m}}\right)$$
$$f_3 = 728 \text{ Hz}$$

Statement: The first three harmonic frequencies are 146 Hz, 437 Hz, and 728 Hz. As the temperature increases, the harmonic frequencies of the clarinet increase. Therefore, the pitch of the clarinet would increase, possibly making the listener's experience less pleasant.

39. From their descriptions, Becky is probably at a node and Rajiv is at an antinode. That means the closest they can be to each other is one quarter of a wavelength.

Given: f = 88 Hz; v = 343 m/s

Required: $\frac{\lambda}{4}$

Analysis: $v = 331.4 \text{ m/s} + (0.606 \text{ m/s/°C})T$;

$$\lambda = \frac{v}{f}$$
$$\frac{\lambda}{4} = \frac{v}{4f}$$

Solution:

$$\frac{\lambda}{4} = \frac{v}{4f}$$
$$= \frac{343 \text{ m/s}}{4(88 \text{ Hz})}$$
$$\frac{\lambda}{4} = 0.97 \text{ m}$$

Statement: Assuming that Becky is at a node and Rajiv is at an antinode, the minimum distance between them is 0.97 m.

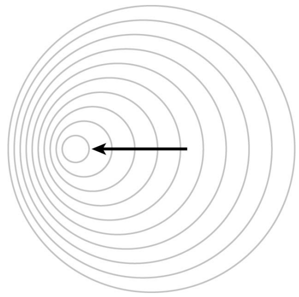
40. Pressing down on the strings creates a new fixed end to the string, shortening the length that the wave travels. By reducing the wavelength of the standing waves, the frequency of the sound changes.

41. (a) The amplitude of the beats is the sum of the amplitudes of the interfering waves.

(b) The beat will sound like an even rising and falling of the combined sound.

42. Answers may vary. Sample answer: Resonance is the condition in which the frequency of a wave equals the natural frequency (or resonant frequency) of the wave's medium.

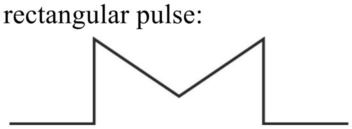
43. The arrow is pointing in the opposite direction.



44. Answers may vary. Sample answers:
(a) Frequency decreases because the observer is moving away from the source.
(b) Frequency increases because the observer is moving toward the source.
(c) No change in frequency because the observer is staying the same distance from the source.
45. Answers may vary. Sample answer:
The thousands of waves in a body of water occasionally pass through each other and produce an interference pattern that produces an abnormally large wave.

Analysis and Application

46. Answers may vary. Sample answers:
(a) The waves pass through each other and continue on their paths around the stadium.
(b) The amplitude at the points of constructive interference would not be the sum of the two amplitudes because the wave can only be as tall as the people participating.
47. The interference will result in a 2 cm triangular dip in the rectangular pulse:



48. Given: L = 4.0 m; F_T = 1240 N; μ = 1.9 kg/m; two fixed ends
Required: f_1; f_2; f_3
Analysis:

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

$$L_n = \frac{n\lambda}{2} = \frac{n}{2}\left(\frac{v}{f_n}\right)$$

$$f_n = \frac{n}{2}\left(\frac{v}{L_n}\right)$$

Solution: Determine the speed of a wave along the rope:

$$v = \sqrt{\frac{F_T}{\mu}} = \sqrt{\frac{1240\ \text{N}}{1.9\ \text{kg/m}}}$$

v = 652.6 m/s (two extra digits carried)

Determine the first three harmonics:

$$f_n = \frac{n}{2}\left(\frac{v}{L_n}\right)$$

$$f_1 = \frac{1}{2}\left(\frac{25.55\ \text{m/s}}{4.0\ \text{m}}\right)$$

$$f_1 = 3.2\ \text{Hz}$$

$$f_n = \frac{n}{2}\left(\frac{v}{L_n}\right)$$

$$f_2 = \frac{2}{2}\left(\frac{25.55\ \text{m/s}}{4.0\ \text{m}}\right)$$

$$f_2 = 6.4\ \text{Hz}$$

$$f_n = \frac{n}{2}\left(\frac{v}{L_n}\right)$$

$$f_3 = \frac{3}{2}\left(\frac{25.55\ \text{m/s}}{4.0\ \text{m}}\right)$$

$$f_3 = 9.6\ \text{Hz}$$

Statement: The first three harmonic frequencies of the rope are 3.2 Hz, 6.4 Hz, and 9.6 Hz.
49. For a source with fixed and free ends, the length of the object is one quarter of the wavelength of the first harmonic.
Given: f = 280.0 Hz; v = 343 m/s; fixed and free ends
Required: L_1
Analysis: $L_1 = \frac{\lambda}{4}$
Solution:

$$L_1 = \frac{\lambda}{4} = \frac{1}{4}\left(\frac{v}{f}\right) = \frac{1}{4}\left(\frac{343\ \text{m/s}}{280.0\ \text{Hz}}\right) = 0.306\ \text{m}$$

$$L_1 = 30.6\ \text{cm}$$

Statement: To achieve a resonant frequency of 280.0 Hz, the length of the pipe must be 0.306 m, or 30.6 cm.

50. (a) As the length of the column of air increases, the frequency increases.

(b) The frequency changes because the length of the column of air is decreased when water is added to the bottle.

51. (a) The difference between consecutive harmonics equals the fundamental overtone (or first harmonic) since they are all multiples of the fundamental overtone.

730 Hz – 584 Hz = 146 Hz

584 Hz – 438 Hz = 146 Hz

The fundamental overtone is 146 Hz.

(b) Note: After the first printing, the following information was added to question 51(b):
"Assume the speed of sound is 343 m/s."
The correct answer is still 1.17 m.

Given: f_1 = 146 Hz; two free ends; v = 343 m/s

Required: L_1

Analysis:

$$L_1 = \frac{\lambda}{2}$$

Solution:

$$\begin{aligned} L_1 &= \frac{\lambda}{2} \\ &= \frac{1}{2}\left(\frac{v}{f}\right) \\ &= \frac{1}{2}\left(\frac{343 \text{ m/s}}{146 \text{ Hz}}\right) \end{aligned}$$

$$L_1 = 1.17 \text{ m}$$

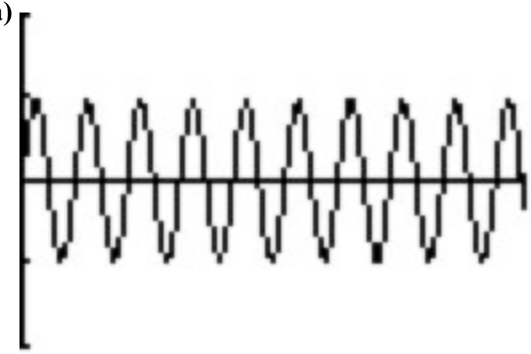
Statement: The length of the tube is 1.17 m.

52. Answers may vary. Sample answer:
The interference pattern of the waves coming from the two sources would be different at the two points. One person could experience lots of destructive interference, while the other person experiences lots of constructive interference, resulting in a very different concert experience. This phenomenon is not typically noticeable at actual events because there are usually more speakers, sound reflects off other surfaces, and there are no pure tones.

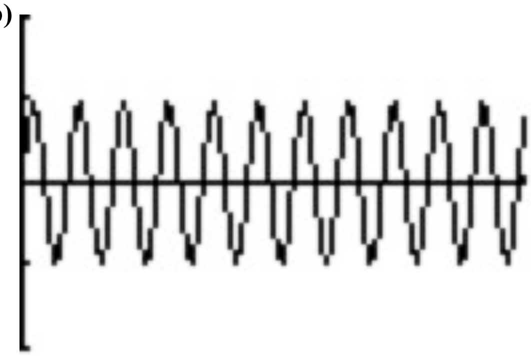
53. Answers may vary. Sample answer:
If there is a standing wave, then the sound waves from the tuning fork should be reflected along the air column and return to the open end exactly as they entered. That means that the amplitude of the tuning fork's sound wave will be doubled by the interference with its reflection. You should hear the steady sound of the frequency of the tuning fork doubled.

54. Note: After the first printing, the value given for xmax was changed to "10 or 20" (was 60). The answer below reflects this change.

(a)

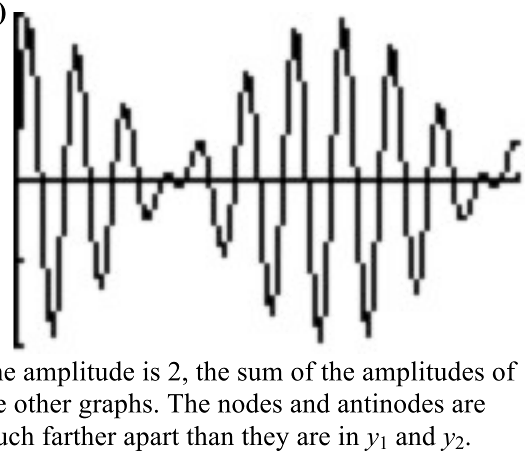


(b)



(c) The graphs have the same amplitude, 1. The nodes and antinodes of y_2 are closer together than they are in y_1.

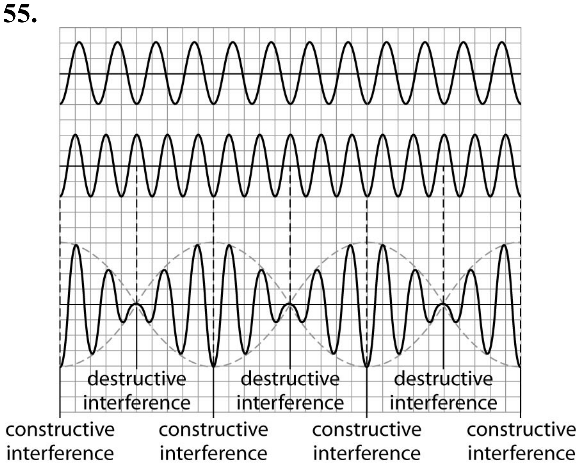
(d)



The amplitude is 2, the sum of the amplitudes of the other graphs. The nodes and antinodes are much farther apart than they are in y_1 and y_2.

(e) This illustrates the productions of beats because this is not a standing wave but a period change in intensity.

55.



56. Answers may vary. Students might discuss the use of acoustic materials in an auditorium. Factors to be considered might be cost effectiveness, availability, design, and government standards.

57. Given: v_{source} = 0 m/s; f_0 = 16.02 Hz; $v_{detector}$ = 50.0 m/s; v_{sound} = 1560 m/s

Required: f_{obs}

Analysis:

$$f_{obs} = \left(\frac{v_{sound} + v_{detector}}{v_{sound} + v_{source}}\right) f_0$$

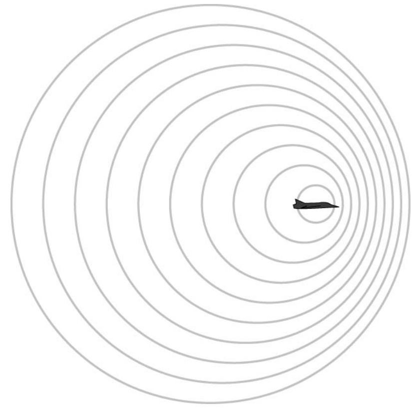
Solution:

$$\begin{aligned} f_{obs} &= \left(\frac{v_{sound} + v_{detector}}{v_{sound} + v_{source}}\right) f_0 \\ &= \left(\frac{1560 \text{ m/s} + 50.0 \text{ m/s}}{1560 \text{ m/s} + 0 \text{ m/s}}\right)(16.02 \text{ Hz}) \\ &= \left(\frac{1610 \cancel{\text{m/s}}}{1560 \cancel{\text{m/s}}}\right)(16.02 \text{ Hz}) \\ f_{obs} &= 16.5 \text{ Hz} \end{aligned}$$

Statement: The frequency observed by the marine biologist in the submarine is 16.5 Hz.

58. Answers may vary. Sample answers:

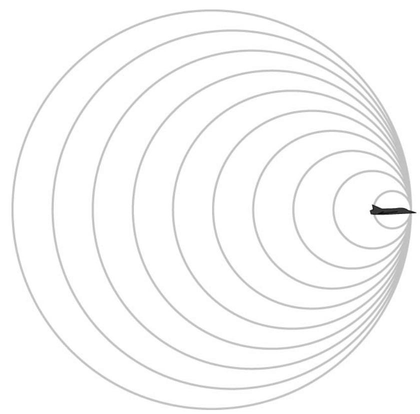
(a)



(b) The distance between the consecutive rings is very small toward the right side of the diagram. The distance between rings on the right side of the jet will continue to shrink as the jet approaches the speed of sound.

When the jet is moving at the speed of the sound, the rings will all touch at the right of the diagram.

(c)



(d) When the jet breaks a sound barrier, the jet is moving at the same speed as all the sound waves it produces. All those waves arrive at the same time, so they build up into a huge sound called the sonic boom.

Evaluation

59. Answers may vary. Sample answer:

As the satellite approaches the detector, the frequency of the signal increases. This in turn will alter the beat frequency. When directly overhead, the beat frequency is constant, and when receding the beat frequency will decrease.

60. Answers may vary. Sample answer:
The phenomenon of resonance is being exhibited. The stationary ripples on the surface of the water in the glass are standing waves. Some of the vibrations from the dryer are vibrating at the same natural frequency as the water in the glass, causing the standing waves. Much of the energy from the original vibration is retained because it travels through the dryer, through the floor, through the table, and up to the glass of water.
61. Answers may vary. Sample answer:
The transmitting medium would still have to be moving at an appreciable percentage of the speed of the sound. The receiver would experience the sound waves arriving at a greater speed, thus reducing the wavelength. This in turn changes the frequency of the sound.

Reflect on Your Learning

62. Answers may vary. Sample answer:
Sections 9.3 and 9.4 build on what was introduced in Sections 9.2 and 9.1. For example, beats are an application of constructive interference while damping is an application of destructive interference.
63. Answers may vary. Students might reflect upon a discovery made in one of the mini investigations, such as the appearance of an acoustic beat pattern projected on a computer screen or the phenomenon of rogue waves.
64. Answers may vary. Students might reflect upon an important idea such as resonance, which became clearer when observing and explaining some real-life examples, such as with a swing, a rope, or a guitar string.
65. Answers may vary. Sample answer:
The dangers of waves are exhibited by the concepts of rogue waves and sonic boom. On the other hand, damping and destructive interference exhibit the benefits of learning about and applying waves.

Research

66. Answers may vary. Students should report on one family of instruments, including information on lengths of strings or air columns, fixed ends versus free ends, wave speed, and frequency.
67. Answers may vary. Sample answers:
(a) Energy-conversion buoys generate energy using an action that is similar to the action of a piston by having a fixed shaft surrounded by a floating buoy that moves in the same up and down pattern with the waves.
(b) One source suggests that a single buoy could produce 250 kW.
(c) The researchers in Uppsala, Sweden, are using buoys attached by a line to rods on the ocean floor to move a rod up and down in a shaft to generate electricity.
(d) Approximately 10 % of Sweden's energy needs are expected to be met using slow-moving waves.
68. (a) Hypersonic sound is new technology that uses wireless ultrasonic signals and new techniques to produce sound located only in specific areas. It creates the equivalent of a laser beam of sound from a speaker instead of an even dispersal in all directions.
(b) The technology works through interference by simultaneously sending out ultrasonic waves which cannot be heard. When these waves hit an object, the interference creates the intended sound waves. Using this technology, you could point the hypersonic sound speaker at an object, and the audible sound waves will be created at the object instead of the speaker.
69. (a), (b) Radar waves emitted from a transmitter in the police car are reflected by an approaching car and arrive back at a radar receiver in the police car with a slightly higher frequency.
(c) Answers may vary. Students could describe how Doppler radar is used to understand the movement and location of weather systems. Or students could investigate the meaning of "redshift" and "blueshift" in relation to the motions of stars and galaxies. They could also research how radar units are used to detect the speed of a baseball thrown by a pitcher.
70. Answers may vary. Sample answer:
Near the southwest tip of Africa, a major current moves down the southwest coast of Africa, and major winds move up the southwest coast of Africa, creating a possible condition for the formation of rogue waves.