CHAPTER

14 Vibrations and Waves

Practice Problems

14.1 Periodic Motion pages 375–380

page 378

1. How much force is necessary to stretch a spring 0.25 m when the spring constant is 95 N/m?

$$F = kx$$
$$= (95\text{ N/m})(0.25\text{ m})$$
$$= 24\text{ N}$$

2. A spring has a spring constant of 56 N/m. How far will it stretch when a block weighing 18 N is hung from its end?

$$F = kx$$
$$x = \frac{F}{k} = \frac{18\text{ N}}{56\text{ N/m}} = 0.32\text{ m}$$

3. What is the spring constant of a spring that stretches 12 cm when an object weighing 24 N is hung from it?

$$F = kx$$
$$k = \frac{F}{x}$$
$$= \frac{24\text{ N}}{0.12\text{ m}}$$
$$= 2.0\times10^2\text{ N/m}$$

4. A spring with a spring constant of 144 N/m is compressed by a distance of 16.5 cm. How much elastic potential energy is stored in the spring?

$$PE_{sp} = \frac{1}{2}kx^2$$
$$= \frac{1}{2}(144\text{ N/m})(0.165\text{ m})^2 = 1.96\text{ J}$$

5. A spring has a spring constant of 256 N/m. How far must it be stretched to give it an elastic potential energy of 48 J?

$$PE_{sp} = \frac{1}{2}kx^2$$
$$x = \sqrt{\frac{2PE_{sp}}{k}} = \sqrt{\frac{(2)(48\text{ J})}{256\text{ N/m}}} = 0.61\text{ m}$$

page 379

6. What is the period on Earth of a pendulum with a length of 1.0 m?

$$T = 2\pi\sqrt{\frac{l}{g}} = 2\pi\sqrt{\frac{1.0\text{ m}}{9.80\text{ m/s}^2}} = 2.0\text{ s}$$

7. How long must a pendulum be on the Moon, where $g = 1.6\text{ m/s}^2$, to have a period of 2.0 s?

$$T = 2\pi\sqrt{\frac{l}{g}}$$
$$l = g\left(\frac{T}{2\pi}\right)^2 = (1.6\text{ m/s}^2)\left(\frac{2.0\text{ s}}{2\pi}\right)^2 = 0.16\text{ m}$$

8. On a planet with an unknown value of g, the period of a 0.75-m-long pendulum is 1.8 s. What is g for this planet?

$$T = 2\pi\sqrt{\frac{l}{g}}$$
$$g = l\left(\frac{2\pi}{T}\right)^2 = (0.75\text{ m})\left(\frac{2\pi}{1.8\text{ s}}\right)^2 = 9.1\text{ m/s}^2$$

Section Review

14.1 Periodic Motion pages 375–380

page 380

9. **Hooke's Law** Two springs look alike but have different spring constants. How could you determine which one has the greater spring constant?

Hang the same object from both springs. The one that stretches less has the greater spring constant.

10. **Hooke's Law** Objects of various weights are hung from a rubber band that is suspended from a hook. The weights of the objects are plotted on a graph against the

stretch of the rubber band. How can you tell from the graph whether or not the rubber band obeys Hooke's law?

If the graph is a straight line, the rubber band obeys Hooke's law. If the graph is curved, it does not.

11. Pendulum How must the length of a pendulum be changed to double its period? How must the length be changed to halve the period?

$$PE_{sp} = \frac{1}{2}kx^2\text{, so}$$

$$\frac{PE_1}{PE_2} = \frac{x_1^{\,2}}{x_2^{\,2}}$$

$$= \frac{(0.40\text{ m})^2}{(0.20\text{ m})^2}$$

$$= 4.0$$

The energy of the first spring is 4.0 times greater than the energy of the second spring.

12. Energy of a Spring What is the difference between the energy stored in a spring that is stretched 0.40 m and the energy stored in the same spring when it is stretched 0.20 m?

$$T = 2\pi\sqrt{\frac{l}{g}}\text{, so } \frac{T_2}{T_1} = \sqrt{\frac{l_2}{l_1}}$$

To double the period:

$$\frac{T_2}{T_1} = \sqrt{\frac{l_2}{l_1}} = 2\text{, so } \frac{l_2}{l_1} = 4$$

The length must be quadrupled.

To halve the period:

$$\frac{T_2}{T_1} = \sqrt{\frac{l_2}{l_1}} = \frac{1}{2}\text{, so } \frac{l_2}{l_1} = \frac{1}{4}$$

The length is reduced to one-fourth its original length.

13. Resonance If a car's wheel is out of balance, the car will shake strongly at a specific speed, but not when it is moving faster or slower than that speed. Explain.

At that speed, the tire's rotation frequency matches the resonant frequency of the car.

14. Critical Thinking How is uniform circular motion similar to simple harmonic motion? How are they different?

Both are periodic motions. In uniform circular motion, the accelerating force is not proportional to the displacement. Also, simple harmonic motion is one-dimensional and uniform circular motion is two-dimensional.

Practice Problems

14.2 Wave Properties pages 381–386

page 386

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

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

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

$$= \frac{515\text{ m}}{1.50\text{ s}}$$

$$= 343\text{ m/s}$$

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

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

$$= \frac{1}{436\text{ Hz}}$$

$$= 2.29\times10^{-3}\text{ s}$$

c. What is the wave's wavelength?

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

$$= \frac{343\text{ m/s}}{436\text{ Hz}}$$

$$= 0.787\text{ m}$$

16. A hiker shouts toward a vertical cliff 465 m away. The echo is heard 2.75 s later.

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

$$v = \frac{d}{t} = \frac{(2)(465\text{ m})}{2.75\text{ s}} = 338\text{ m/s}$$

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

$$v = \lambda f\text{, so } f = \frac{v}{\lambda} = \frac{338\ \text{m/s}}{0.750\ \text{m}} = 451\ \text{Hz}$$

c. What is the period of the wave?

$$T = \frac{1}{f} = \frac{1}{451\ \text{Hz}} = 2.22\times10^{-3}\ \text{s}$$

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

at a lower frequency, because wavelength varies inversely with frequency

18. What is the speed of a periodic wave disturbance that has a frequency of 3.50 Hz and a wavelength of 0.700 m?

$$v = \lambda f = (0.700\ \text{m})(3.50\ \text{Hz}) = 2.45\ \text{m/s}$$

19. The speed of a transverse wave in a string is 15.0 m/s. If a source produces a disturbance that has a frequency of 6.00 Hz, what is its wavelength?

$$v = \lambda f\text{, so } \lambda = \frac{v}{f} = \frac{15.0\ \text{m/s}}{6.00\ \text{Hz}} = 2.50\ \text{m}$$

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

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

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

$$\lambda = vT\text{, so}$$

$$v = \frac{\lambda}{T} = \frac{1.20\ \text{cm}}{0.0200\ \text{s}} = 60.0\ \text{cm/s} = 0.600\ \text{m/s}$$

21. A periodic longitudinal wave that has a frequency of 20.0 Hz travels along a coil spring. If the distance between successive compressions is 0.600 m, what is the speed of the wave?

$$v = \lambda f = (0.600\ \text{m})(20.0\ \text{Hz}) = 12.0\ \text{m/s}$$

Section Review

14.2 Wave Properties pages 381–386

page 386

22. Speed in Different Media If you pull on one end of a coiled-spring toy, does the pulse reach the other end instantaneously? What happens if you pull on a rope? What happens if you hit the end of a metal rod? Compare and contrast the pulses traveling through these three materials.

It takes time for the pulse to reach the other end in each case. It travels faster on the rope than on the spring, and fastest in the metal rod.

23. Wave Characteristics You are creating transverse waves in a rope by shaking your hand from side to side. Without changing the distance that your hand moves, you begin to shake it faster and faster. What happens to the amplitude, wavelength, frequency, period, and velocity of the wave?

The amplitude and velocity remain unchanged, but the frequency increases while the period and the wavelength decrease.

24. Waves Moving Energy Suppose that you and your lab partner are asked to demonstrate that a transverse wave transports energy without transferring matter. How could you do it?

Tie a piece of yarn somewhere near the middle of a rope. With your partner holding one end of the rope, shake the other end up and down to create a transverse wave. Note that while the wave moves down the rope, the yarn moves up and down but stays in the same place on the rope.

25. Longitudinal Waves Describe longitudinal waves. What types of media transmit longitudinal waves?

In longitudinal waves, the particles of the medium vibrate in a direction parallel to the motion of the wave.

Nearly all media—solids, liquids, and gases—transmit longitudinal waves.

26. **Critical Thinking** If a raindrop falls into a pool, it creates waves with small amplitudes. If a swimmer jumps into a pool, waves with large amplitudes are produced. Why doesn't the heavy rain in a thunderstorm produce large waves?

The energy of the swimmer is transferred to the wave in a small space over a short time, whereas the energy of the raindrops is spread out in area and time.

Section Review

14.3 Wave Behavior pages 387–391

page 391

27. **Waves at Boundaries** Which of the following wave characteristics remain unchanged when a wave crosses a boundary into a different medium: frequency, amplitude, wavelength, velocity, and/or direction?

Frequency remains unchanged. In general, amplitude, wavelength, and velocity will change when a wave enters a new medium. Direction may or may not change, depending on the original direction of the wave.

28. **Refraction of Waves** Notice in **Figure 14-17a** how the wave changes direction as it passes from one medium to another. Can two-dimensional waves cross a boundary between two media without changing direction? Explain.

Yes, if they strike the boundary while traveling normal to its surface, or if they have the same speed in both media.

29. **Standing Waves** In a standing wave on a string fixed at both ends, how is the number of nodes related to the number of antinodes?

The number of nodes is always one greater than the number of antinodes.

30. **Critical Thinking** As another way to understand wave reflection, cover the right-hand side of each drawing in **Figure 14-13a** with a piece of paper. The edge of the paper should be at point N, the node. Now, concentrate on the resultant wave, shown in darker blue. Note that it acts like a wave reflected from a boundary. Is the boundary a rigid wall, or is it open-ended? Repeat this exercise for **Figure 14-13b.**

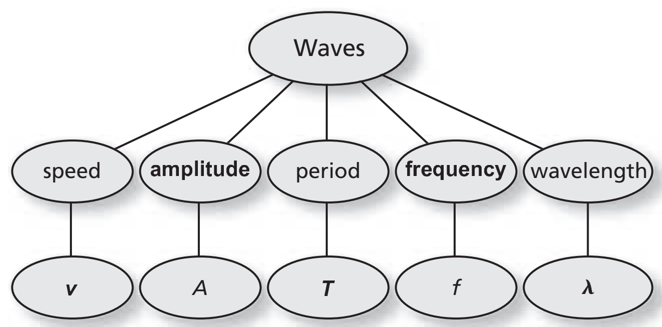
Figure 14-14a behaves like a rigid wall because the reflected wave is inverted; 14-14b behaves like an open end because the boundary is an antinode and the reflected wave is not inverted.

Chapter Assessment

Concept Mapping

page 396

31. Complete the concept map using the following terms and symbols: *amplitude, frequency, v, λ, T*.



Mastering Concepts

page 396

32. What is periodic motion? Give three examples of periodic motion. (14.1)

Periodic motion is motion that repeats in a regular cycle. Examples include oscillation of a spring, swing of a simple pendulum, and uniform circular motion.

33. What is the difference between frequency and period? How are they related? (14.1)

Frequency is the number of cycles or repetitions per second, and period is the time required for one cycle. Frequency is the inverse of the period.

34. What is simple harmonic motion? Give an example of simple harmonic motion. (14.1)

Simple harmonic motion is periodic motion that results when the restoring force on an object is directly proportional to its displacement. A block bouncing on the end of a spring is one example.

35. If a spring obeys Hooke's law, how does it behave? (14.1)

The spring stretches a distance that is directly proportional to the force applied to it.

36. How can the spring constant of a spring be determined from a graph of force versus displacement? (14.1)

The spring constant is the slope of the graph of *F* versus *x*.

37. How can the potential energy in a spring be determined from the graph of force versus displacement? (14.1)

The potential energy is the area under the curve of the graph of *F* versus *x*.

38. Does the period of a pendulum depend on the mass of the bob? The length of the string? Upon what else does the period depend? (14.1)

no; yes; the acceleration of gravity, *g*

39. What conditions are necessary for resonance to occur? (14.1)

Resonance will occur when a force is applied to an oscillating system at the same frequency as the natural frequency of the system.

40. How many general methods of energy transfer are there? Give two examples of each. (14.2)

Two. Energy is transferred by particle transfer and by waves. There are many examples that can be given of each: a baseball and a bullet for particle transfer; sound waves and light waves.

41. What is the primary difference between a mechanical wave and an electromagnetic wave? (14.2)

The primary difference is that mechanical waves require a medium to travel through and electromagnetic waves do not need a medium.

42. What are the differences among transverse, longitudinal, and surface waves? (14.2)

A transverse wave causes the particles of the medium to vibrate in a direction that is perpendicular to the direction in which the wave is moving. A longitudinal wave causes the particles of the medium to vibrate in a direction parallel with the direction of the wave. Surface waves have characteristics of both.

43. Waves are sent along a spring of fixed length. (14.2)

a. Can the speed of the waves in the spring be changed? Explain.

Speed of the waves depends only on the medium and cannot be changed.

b. Can the frequency of a wave in the spring be changed? Explain.

Frequency can be changed by changing the frequency at which the waves are generated.

44. What is the wavelength of a wave? (14.2)

Wavelength is the distance between two adjacent points on a wave that are in phase.

45. Suppose you send a pulse along a rope. How does the position of a point on the rope before the pulse arrives compare to the point's position after the pulse has passed? (14.2)

Once the pulse has passed, the point is exactly as it was prior to the advent of the pulse.

46. What is the difference between a wave pulse and a periodic wave? (14.2)

A pulse is a single disturbance in a medium, whereas a periodic wave consists of several adjacent disturbances.

47. Describe the difference between wave frequency and wave velocity. (14.2)

Frequency is the number of vibrations per second of a part of the medium. Velocity describes the motion of the wave through the medium.

48. Suppose you produce a transverse wave by shaking one end of a spring from side to side. How does the frequency of your hand compare with the frequency of the wave? (14.2)

They are the same.

49. When are points on a wave in phase with each other? When are they out of phase? Give an example of each. (14.2)

Points are in phase when they have the same displacement and the same velocity. Otherwise, the points are out of phase. Two crests are in phase with each other. A crest and a trough are out of phase with each other.

50. What is the amplitude of a wave and what does it represent? (14.2)

Amplitude is the maximum displacement of a wave from the rest or equilibrium position. The amplitude of the wave represents the amount of energy transferred.

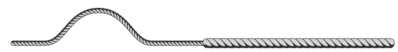
51. Describe the relationship between the amplitude of a wave and the energy it carries. (14.2)

The energy carried by a wave is proportional to the square of its amplitude.

52. When a wave reaches the boundary of a new medium, what happens to it? (14.3)

Part of the wave can be reflected and part of the wave can be transmitted into the new medium.

53. When a wave crosses a boundary between a thin and a thick rope, as shown in **Figure 14-18,** its wavelength and speed change, but its frequency does not. Explain why the frequency is constant. (14.3)



■ **Figure 14-18**

The frequency depends only on the rate at which the thin rope is shaken and the thin rope causes the vibrations in the thick rope.

54. How does a spring pulse reflected from a rigid wall differ from the incident pulse? (14.3)

The reflected pulse will be inverted.

55. Describe interference. Is interference a property of only some types of waves or all types of waves? (14.3)

The superposition of two or more waves is interference. The superposition of two waves with equal but opposite amplitudes results in destructive interference. The superposition of two waves with amplitudes in the same direction results in constructive interference; all waves; it is a prime test for wave nature.

56. What happens to a spring at the nodes of a standing wave? (14.3)

Nothing, the spring does not move.

57. Violins A metal plate is held fixed in the center and sprinkled with sugar. With a violin bow, the plate is stroked along one edge and made to vibrate. The sugar begins to collect in certain areas and move away from others. Describe these regions in terms of standing waves. (14.3)

Bare areas are antinodal regions where there is maximum vibration. Sugar-covered areas are nodal regions where there is no vibration.

58. If a string is vibrating in four parts, there are points where it can be touched without disturbing its motion. Explain. How many of these points exist? (14.3)

A standing wave exists and the string can be touched at any of its five nodal points.

59. Wave fronts pass at an angle from one medium into a second medium, where they travel with a different speed. Describe two changes in the wave fronts. What does not change? (14.3)

The wavelength and direction of the wave fronts change. The frequency does not change.

Applying Concepts

page 397

60. A ball bounces up and down on the end of a spring. Describe the energy changes that take place during one complete cycle. Does the total mechanical energy change?

At the bottom of the motion, the elastic potential energy is at a maximum, while gravitational potential energy is at a minimum and the kinetic energy is zero. At the equilibrium position, the *KE* is at a maximum and the elastic potential energy is zero. At the top of the bounce, the *KE* is zero, the gravitational potential energy is at a maximum, and the elastic potential energy is at a maximum. The total mechanical energy is conserved.

61. Can a pendulum clock be used in the orbiting *International Space Station?* Explain.

No, the space station is in free-fall, and therefore, the apparent value of *g* is zero. The pendulum will not swing.

62. Suppose you hold a 1-m metal bar in your hand and hit its end with a hammer, first, in a direction parallel to its length, and second, in a direction at right angles to its length. Describe the waves produced in the two cases.

In the first case, longitudinal waves; in the second case, transverse waves.

63. Suppose you repeatedly dip your finger into a sink full of water to make circular waves. What happens to the wavelength as you move your finger faster?

The frequency of the waves will increase; the speed will remain the same; the wavelength will decrease.

64. What happens to the period of a wave as the frequency increases?

As the frequency increases, the period decreases.

65. What happens to the wavelength of a wave as the frequency increases?

As the frequency increases, the wavelength decreases.

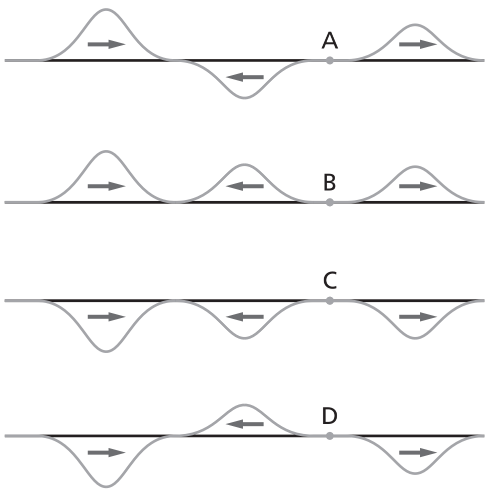
66. Suppose you make a single pulse on a stretched spring. How much energy is required to make a pulse with twice the amplitude?

approximately two squared, or four times the energy

67. You can make water slosh back and forth in a shallow pan only if you shake the pan with the correct frequency. Explain.

The period of the vibration must equal the time for the wave to go back and forth across the pan to create constructive interference.

68. In each of the four waves in **Figure 14-19,** the pulse on the left is the original pulse moving toward the right. The center pulse is a reflected pulse; the pulse on the right is a transmitted pulse. Describe the rigidity of the boundaries at A, B, C, and D.



■ **Figure 14-19**

Boundary A is more rigid; boundary B is less rigid; boundary C is less rigid; boundary D is more rigid.

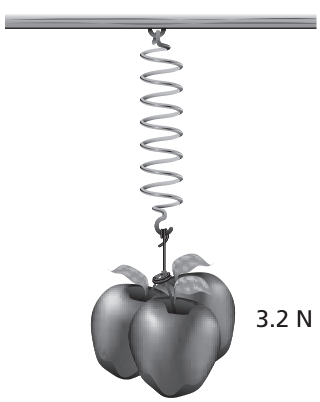
Mastering Problems

14.1 Periodic Motion

pages 397–398

Level 1

69. A spring stretches by 0.12 m when some apples weighing 3.2 N are suspended from it, as shown in **Figure 14-20.** What is the spring constant of the spring?



■ **Figure 14-20**

$\boldsymbol{F = kx,}$

$$\text{so } k = \frac{F}{x} = \frac{3.2\text{ N}}{0.12\text{ m}} = 27\text{ N/m}$$

70. **Car Shocks** Each of the coil springs of a car has a spring constant of 25,000 N/m. How much is each spring compressed if it supports one-fourth of the car's 12,000-N weight?

$\boldsymbol{F = kx,}$

$$\text{so } x = \frac{F}{k}$$

$$= \frac{\left(\frac{1}{4}\right)(12{,}000\text{ N})}{25{,}000\text{ N/m}}$$

$$= 0.12\text{ m}$$

71. How much potential energy is stored in a spring with a spring constant of 27 N/m if it is stretched by 16 cm?

$$PE_{sp} = \frac{1}{2}kx^2$$

$$= \left(\frac{1}{2}\right)(27\text{ N/m})(0.16\text{ m})^2 = 0.35\text{ J}$$

Level 2

72. **Rocket Launcher** A toy rocket-launcher contains a spring with a spring constant of 35 N/m. How far must the spring be compressed to store 1.5 J of energy?

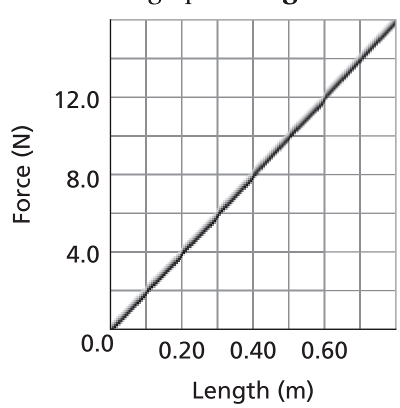
$$PE_{sp} = \frac{1}{2}kx^2,$$

$$\text{so } x = \sqrt{\frac{2PE_{sp}}{k}} = \sqrt{\frac{(2)(1.5\text{ J})}{35\text{ N/m}}}$$

$$= 0.29\text{ m}$$

Level 3

73. Force-versus-length data for a spring are plotted on the graph in **Figure 14-21.**



■ **Figure 14-21**

a. What is the spring constant of the spring?

$k = \text{slope}$

$= \frac{\Delta F}{\Delta x} = \frac{12.0\text{ N} - 4.0\text{ N}}{0.6\text{ m} - 0.2\text{ m}}$

$= 20\text{ N/m}$

b. What is the energy stored in the spring when it is stretched to a length of 50.0 cm?

$PE_{sp} = \text{area} = \frac{1}{2}bh$

$= \left(\frac{1}{2}\right)(0.500\text{ m})(10.0\text{ N}) = 2.50\text{ J}$

74. How long must a pendulum be to have a period of 2.3 s on the Moon, where $g = 1.6\text{ m/s}^2$?

$T = 2\pi\sqrt{\frac{l}{g}}$, so $l = \frac{T^2 g}{4\pi^2}$

$= \frac{(2.3\text{ s})^2(1.6\text{ m/s}^2)}{4\pi^2} = 0.21\text{ m}$

14.2 Wave Properties
page 398

Level 1

75. Building Motion The Sears Tower in Chicago, shown in **Figure 14-22,** sways back and forth in the wind with a frequency of about 0.12 Hz. What is its period of vibration?

■ **Figure 14-22**

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

$T = \frac{1}{f} = \frac{1}{0.12\text{ Hz}} = 8.3\text{ s}$

76. Ocean Waves An ocean wave has a length of 12.0 m. A wave passes a fixed location every 3.0 s. What is the speed of the wave?

$v = \lambda f = \lambda\left(\frac{1}{T}\right) = (12.0\text{ m})\left(\frac{1}{3.0\text{ s}}\right)$

$= 4.0\text{ m/s}$

77. Water waves in a shallow dish are 6.0-cm long. At one point, the water moves up and down at a rate of 4.8 oscillations/s.

a. What is the speed of the water waves?

$v = \lambda f$

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

b. What is the period of the water waves?

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

78. Water waves in a lake travel 3.4 m in 1.8 s. The period of oscillation is 1.1 s.

a. What is the speed of the water waves?

$v = \frac{d}{t} = \frac{3.4\text{ m}}{1.8\text{ s}} = 1.9\text{ m/s}$

b. What is their wavelength?

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

$= (1.9\text{ m/s})(1.1\text{ s})$

$= 2.1\text{ m}$

Level 2

79. Sonar A sonar signal of frequency 1.00×10^6 Hz has a wavelength of 1.50 mm in water.

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

$v = \lambda f$

$= (1.50\times10^{-3}\text{ m})(1.00\times10^6\text{ Hz})$

$= 1.50\times10^3\text{ m/s}$

b. What is its period in water?

$T = \frac{1}{f} = \frac{1}{1.00\times10^6\text{ Hz}}$

$= 1.00\times10^{-6}\text{ s}$

c. What is its period in air?

1.00×10^{-6} s

The period and frequency remain unchanged.

80. A sound wave of wavelength 0.60 m and a velocity of 330 m/s is produced for 0.50 s.

a. What is the frequency of the wave?

$v = \lambda f$

$f = \frac{v}{\lambda} = \frac{330\text{ m/s}}{0.60\text{ m}}$

$= 550\text{ Hz}$

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

$ft = (550\text{ Hz})(0.50\text{ s})$

$= 280$ **complete waves**

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

$d = vt$

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

$= 1.6\times10^2\text{ m}$

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

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

$d = vt$

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

$= 1350\text{ m}$

Level 3

82. Pepe and Alfredo are resting on an offshore raft after a swim. They estimate that 3.0 m separates a trough and an adjacent crest of each surface wave on the lake. They count 12 crests that pass by the raft in 20.0 s. Calculate how fast the waves are moving.

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

$f = \frac{12\text{ waves}}{20.0\text{ s}} = 0.60\text{ Hz}$

$v = \lambda f$

$= (6.0\text{ m})(0.60\text{ Hz})$

$= 3.6\text{ m/s}$

83. Earthquakes The velocity of the transverse waves produced by an earthquake is 8.9 km/s, and that of the longitudinal waves is 5.1 km/s. A seismograph records the arrival of the transverse waves 68 s before the arrival of the longitudinal waves. How far away is the earthquake?

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

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

$t = \frac{(5.1\text{ km/s})(68\text{ s})}{8.9\text{ km/s} - 5.1\text{ km/s}} = 91\text{ s}$

Then putting t back into

$d_T = v_T t = (8.9\text{ km/s})(91\text{ s})$

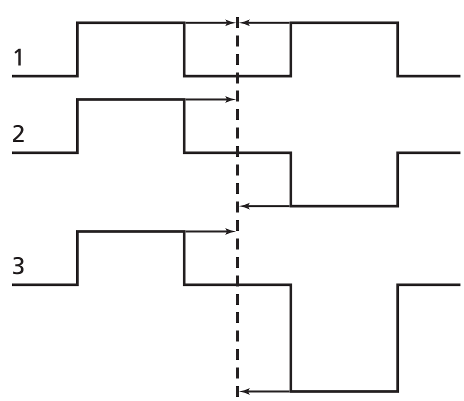
$= 8.1\times10^2\text{ km}$

14.3 Wave Behavior

pages 398–399

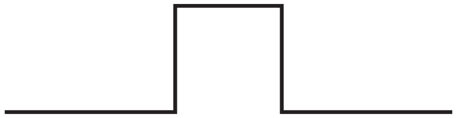
Level 1

84. Sketch the result for each of the three cases shown in **Figure 14-23,** when the centers of the two approaching wave pulses lie on the dashed line so that the pulses exactly overlap.



■ **Figure 14-23**

1. **The amplitude is doubled.**



2. **The amplitudes cancel each other.**

3. **If the amplitude of the first pulse is one-half of the second, the resultant pulse is one-half the amplitude of the second.**

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

$\lambda = 2(1.5\text{ m}) = 3.0\text{ m}$

$v = \lambda f$

$= (3.0\text{ m})(0.30\text{ Hz})$

$= 0.90\text{ m/s}$

Level 2

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

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

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

$$\text{so } t = \frac{d}{v} = \frac{0.63\text{ m}}{265\text{ m/s}} = 2.4\times10^{-3}\text{ s}$$

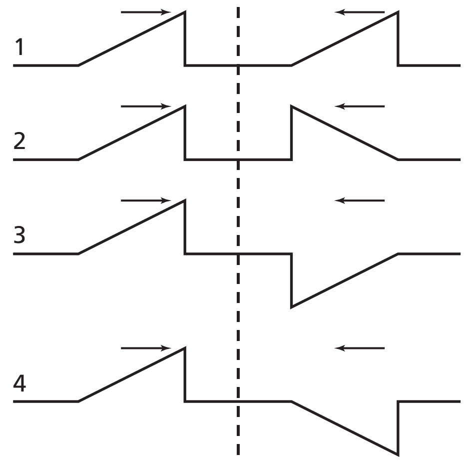
b. When the pulses return, is the string above or below its resting location?

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

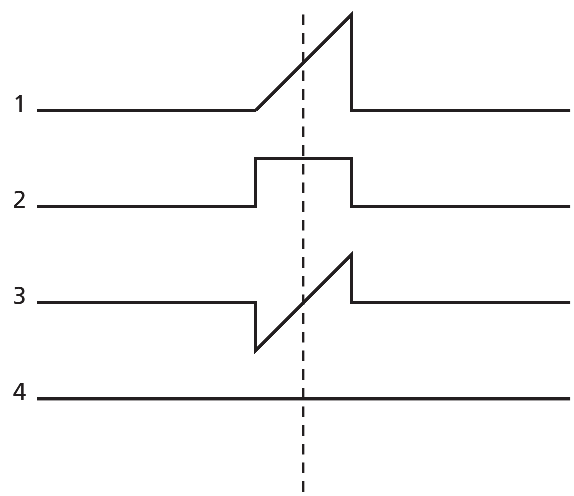
c. If you plucked the string 15 cm from one end of the string, where would the two pulses meet?

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

87. Sketch the result for each of the four cases shown in **Figure 14-24,** when the centers of each of the two wave pulses lie on the dashed line so that the pulses exactly overlap.



■ **Figure 14-24**



Mixed Review

page 399–400

Level 1

88. What is the period of a pendulum with a length of 1.4 m?

$$T = 2\pi\sqrt{\frac{l}{g}}$$

$$= 2\pi\sqrt{\frac{1.4\text{ m}}{9.80\text{ m/s}^2}} = 2.4\text{ s}$$

89. The frequency of yellow light is 5.1×10^{14} Hz. Find the wavelength of yellow light. The speed of light is 3.00×10^{8} m/s.

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

$$= \frac{3.00\times10^{8}\ \text{m/s}}{5.1\times10^{14}\ \text{Hz}}$$

$$= 5.9\times10^{-7}\ \text{m}$$

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

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

$$v = \lambda f$$

$$\lambda_1 = \frac{v}{f_1} = \frac{3.0\times10^{8}\ \text{m/s}}{5.5\times10^{5}\ \text{Hz}}$$

$$= 550\ \text{m}$$

$$\lambda_2 = \frac{v}{f_2} = \frac{3.0\times10^{8}\ \text{m/s}}{1.6\times10^{6}\ \text{Hz}}$$

$$= 190\ \text{m}$$

Range is 190 m to 550 m.

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

$$\lambda = \frac{v}{f} = \frac{3.0\times10^{8}\ \text{m/s}}{8.8\times10^{7}\ \text{Hz}}$$

$$= 3.4\ \text{m}$$

$$\lambda = \frac{v}{f} = \frac{3.0\times10^{8}\ \text{m/s}}{1.08\times10^{8}\ \text{Hz}}$$

$$= 2.8\ \text{m}$$

Range is 2.8 m to 3.4 m.

91. You are floating just offshore at the beach. Even though the waves are steadily moving in toward the beach, you don't move any closer to the beach.

a. What type of wave are you experiencing as you float in the water?

transverse waves

b. Explain why the energy in the wave does not move you closer to shore.

The displacement is perpendicular to the direction of the wave—in this case, up and down.

c. In the course of 15 s you count ten waves that pass you. What is the period of the waves?

$$T = \frac{15\ \text{s}}{10\ \text{waves}} = 1.5\ \text{s}$$

d. What is the frequency of the waves?

$$f = \frac{1}{T} = \frac{1}{1.5\ \text{s}} = 0.67\ \text{Hz}$$

e. You estimate that the wave crests are 3 m apart. What is the velocity of the waves?

$$v = \lambda f = (3\ \text{m})(0.67\ \text{Hz}) = 2\ \text{m/s}$$

f. After returning to the beach, you learn that the waves are moving at 1.8 m/s. What is the actual wavelength of the waves?

$$\lambda = \frac{v}{f} = \frac{1.8\ \text{m/s}}{0.67\ \text{Hz}} = 2.7\ \text{m}$$

Level 2

92. **Bungee Jumper** A high-altitude bungee jumper jumps from a hot-air balloon using a 540-m-bungee cord. When the jump is complete and the jumper is just suspended from the cord, it is stretched 1710 m. What is the spring constant of the bungee cord if the jumper has a mass of 68 kg?

$$k = \frac{F}{x} = \frac{mg}{x} = \frac{(68\ \text{kg})(9.80\ \text{m/s}^2)}{1710\ \text{m} - 540\ \text{m}}$$

$$= 0.57\ \text{N/m}$$

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

a. What fraction of a wavelength is this?

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

b. What is the period of the wave?

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

c. What is the frequency of the wave?

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

94. When a 225-g mass is hung from a spring, the spring stretches 9.4 cm. The spring and mass then are pulled 8.0 cm from this new equilibrium position and released. Find the spring constant of the spring and the maximum speed of the mass.

$$k = \frac{F}{x} = \frac{mg}{x}$$

$$= \frac{(0.225 \text{ kg})(9.80 \text{ m/s}^2)}{0.094 \text{ m}} = 23 \text{ N/m}$$

Maximum velocity occurs when the mass passes through the equilibrium point, where all the energy is kinetic energy. Using the conservation of energy:

$$PE_{sp} = KE_{mass}$$

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

$$v^2 = \frac{kx^2}{m}$$

$$v = \sqrt{\frac{kx^2}{m}} = \sqrt{\frac{(23 \text{ N/m})(0.080 \text{ m})^2}{0.225 \text{ kg}}}$$

$$= 0.81 \text{ m/s}$$

95. **Amusement Ride** You notice that your favorite amusement-park ride seems bigger. The ride consists of a carriage that is attached to a structure so it swings like a pendulum. You remember that the carriage used to swing from one position to another and back again eight times in exactly 1 min. Now it only swings six times in 1 min. Give your answers to the following questions to two significant digits.

a. What was the original period of the ride?

$$T = \frac{1}{f} = \frac{1}{\left(\frac{8 \text{ swings}}{60.0 \text{ s}}\right)} = 7.5 \text{ s}$$

b. What is the new period of the ride?

$$T = \frac{1}{f} = \frac{1}{\left(\frac{6 \text{ swings}}{60.0 \text{ s}}\right)} = 1.0\times10^1 \text{ s}$$

c. What is the new frequency?

$$f = \frac{1}{T} = \frac{1}{1.0\times10^{-1} \text{ s}} = 0.10 \text{ Hz}$$

d. How much longer is the arm supporting the carriage on the larger ride?

Original:

$$l = g\frac{T^2}{4\pi^2}$$

$$= (9.80 \text{ m/s}^2)\frac{(7.5 \text{ s})^2}{4\pi^2}$$

$$= 14 \text{ m}$$

New:

$$l = g\frac{T^2}{4\pi^2}$$

$$= (9.80 \text{ m/s}^2)\frac{(1.0\times10^1 \text{ s})^2}{4\pi^2}$$

$$= 25 \text{ m}$$

The arm on the new structure is 11 m longer.

e. If the park owners wanted to double the period of the ride, what percentage increase would need to be made to the length of the pendulum?

Because of the square relationship, there would need to be a 4 times increase in the length of the pendulum, or a 300% increase.

96. **Clocks** The speed at which a grandfather clock runs is controlled by a swinging pendulum.

a. If you find that the clock loses time each day, what adjustment would you need to make to the pendulum so it will keep better time?

The clock must be made to run faster. The period of the pendulum can be shortened, thus increasing the speed of the clock, by shortening the length of the pendulum.

b. If the pendulum currently is 15.0 cm, by how much would you need to change the length to make the period lessen by 0.0400 s?

$$\Delta T = 2\pi\sqrt{\frac{l_2}{g}} - 2\pi\sqrt{\frac{l_1}{g}}$$

$$\frac{\Delta T}{2\pi} = \sqrt{\frac{l_2}{g}} - \sqrt{\frac{l_1}{g}}$$

$$\frac{\Delta T}{2\pi} = \sqrt{\frac{1}{g}}\sqrt{l_2} - \sqrt{\frac{1}{g}}\sqrt{l_1}$$

$$\frac{\Delta T}{2\pi} = \frac{1}{\sqrt{g}}\sqrt{l_2} - \frac{1}{\sqrt{g}}\sqrt{l_1}$$

$$\frac{\Delta T\sqrt{g}}{2\pi} = \sqrt{l_2} - \sqrt{l_1}$$

$$\sqrt{l_2} = \frac{\Delta T\sqrt{g}}{2\pi} + \sqrt{l_1}$$

$$l_2 = \left(\frac{\Delta T\sqrt{g}}{2\pi} + \sqrt{l_1}\right)^2$$

$$= \left(\frac{(-0.0400\ \text{s})\sqrt{9.80\ \text{m/s}^2}}{2\pi} + \sqrt{0.150\ \text{m}}\right)^2$$

$$= 0.135\ \text{m}$$

The length would need to shorten by

$$l_1 - l_2 = 0.150\ \text{m} - 0.135\ \text{m} = 0.015\ \text{m}$$

97. Bridge Swinging In the summer over the New River in West Virginia, several teens swing from bridges with ropes, then drop into the river after a few swings back and forth.

a. If Pam is using a 10.0-m length of rope, how long will it take her to reach the peak of her swing at the other end of the bridge?

swing to peak $= \frac{1}{2}T$

$$= \pi\sqrt{\frac{l}{g}} = \pi\sqrt{\frac{10.0\ \text{m}}{9.80\ \text{m/s}^2}} = 3.17\ \text{s}$$

b. If Mike has a mass that is 20 kg more than Pam, how would you expect the period of his swing to differ from Pam's?

There should be no difference. *T* is not affected by mass.

c. At what point in the swing is *KE* at a maximum?

At the bottom of the swing, *KE* is at a maximum.

d. At what point in the swing is *PE* at a maximum?

At the top of the swing, *PE* is at a maximum.

e. At what point in the swing is *KE* at a minimum?

At the top of the swing, *KE* is at a minimum.

f. At what point in the swing is *PE* at a minimum?

At the bottom of the swing, *PE* is at a minimum.

98. You have a mechanical fish scale that is made with a spring that compresses when weight is added to a hook attached below the scale. Unfortunately, the calibrations have completely worn off of the scale. However, you have one known mass of 500.0 g that displaces the spring 2.0 cm.

a. What is the spring constant for the spring?

$$F = mg = kx$$

$$k = \frac{mg}{x}$$

$$= \frac{(0.5000\ \text{kg})(9.80\ \text{m/s}^2)}{0.020\ \text{m}}$$

$$= 2.4\times10^2\ \text{N/m}$$

b. If a fish displaces the spring 4.5 cm, what is the mass of the fish?

$$F = mg = kx$$

$$m = \frac{kx}{g}$$

$$= \frac{(2.4\times10^{2}\ \text{N/m})(4.5\times10^{-2}\ \text{m})}{9.80\ \text{m/s}^2}$$

$$= 1.1\ \text{kg}$$

99. Car Springs When you add a 45-kg load to the trunk of a new small car, the two rear springs compress an additional 1.0 cm.

a. What is the spring constant for each of the springs?

$F = mg = (45\ \text{kg})(9.80\ \text{m/s}^2) = 440\ \text{N}$

force per spring = 220 N

$F = kx$, so $k = \frac{F}{x}$

$$k = \frac{220\ \text{N}}{0.010\ \text{m}} = 22{,}000\ \text{N/m}$$

b. How much additional potential energy is stored in each of the car springs after loading the trunk?

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

$$= \left(\frac{1}{2}\right)(22{,}000\ \text{N/m})(0.010\ \text{m})^2$$

$$= 1.1\ \text{J}$$

Level 3

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

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

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

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

$= 1.50\times10^{2}\ \text{m/s}$

and $\mu = \frac{m}{L}$

$$= \frac{1.50\times10^{-2}\ \text{kg}}{5.30\ \text{m}}$$

$$= 2.83\times10^{-3}\ \text{kg/m}$$

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

$F_T = v^2\mu$

$= (1.50\times10^{2}\ \text{m/s})^2(2.83\times10^{-3}\ \text{kg/m})$

$= 63.7\ \text{N}$

Thinking Critically

page 400

101. Analyze and Conclude A 20-N force is required to stretch a spring by 0.5 m.

a. What is the spring constant?

$$F = kx,\ \text{so}\ k = \frac{F}{x} = \frac{20\ \text{N}}{0.5\ \text{m}} = 40\ \text{N/m}$$

b. How much energy is stored in the spring?

$$PE_{sp} = \frac{1}{2}kx^2$$

$$= \left(\frac{1}{2}\right)(40\ \text{N/m})(0.5\ \text{m})^2 = 5\ \text{J}$$

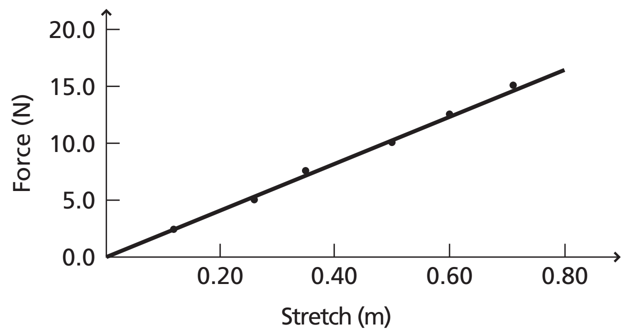
c. Why isn't the work done to stretch the spring equal to the force times the distance, or 10 J?

The force is not constant as the spring is stretched. The average force, 10 N, times the distance does give the correct work.

102. Make and Use Graphs Several weights were suspended from a spring, and the resulting extensions of the spring were measured. **Table 14-1** shows the collected data.

Table 14-1	
Weights on a Spring	
Force, F (N)	Extension, x (m)
2.5	0.12
5.0	0.26
7.5	0.35
10.0	0.50
12.5	0.60
15.0	0.71

a. Make a graph of the force applied to the spring versus the spring length. Plot the force on the *y*-axis.



b. Determine the spring constant from the graph.

The spring constant is the slope.

$$k = \text{slope} = \frac{\Delta F}{\Delta x} = \frac{15.0\ \text{N} - 2.5\ \text{N}}{0.71\ \text{m} - 0.12\ \text{m}} = 21\ \text{N/m}$$

c. Using the graph, find the elastic potential energy stored in the spring when it is stretched to 0.50 m.

The potential energy is the area under the graph.

$$PE_{sp} = \text{area} = \frac{1}{2}bh$$

$$= \left(\frac{1}{2}\right)(0.50\ \text{m})(10.0\ \text{N})$$

$$= 2.5\ \text{J}$$

103. Apply Concepts Gravel roads often develop regularly spaced ridges that are perpendicular to the road, as shown in **Figure 14-25.** This effect, called washboarding, occurs because most cars travel at about the same speed and the springs that connect the wheels to the cars oscillate at about the same frequency. If the ridges on a road are 1.5 m apart and cars travel on it at about 5 m/s, what is the frequency of the springs' oscillation?

■ **Figure 14-25**

$$v = \lambda f$$

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

Writing in Physics

page 400

104. Research Christiaan Huygens' work on waves and the controversy between him and Newton over the nature of light. Compare and contrast their explanations of such phenomena as reflection and refraction. Whose model would you choose as the best explanation? Explain why.

Huygens proposed the wave theory of light and Newton proposed the particle theory of light. The law of reflection can be explained using both theories. Huygen's principle and Newton's particle theory are opposed, however, in their explanation of the law of refraction.

Cumulative Review

page 400

105. A 1400-kg drag racer automobile can complete a one-quarter mile (402 m) course in 9.8 s. The final speed of the automobile is 250 mi/h (112 m/s). (Chapter 11)

a. What is the kinetic energy of the automobile?

$$KE = \frac{1}{2}mv^2$$
$$= \left(\frac{1}{2}\right)(1400\text{ kg})(112\text{ m/s})^2$$
$$= 8.8\times10^6\text{ J}$$

b. What is the minimum amount of work that was done by its engine? Why can't you calculate the total amount of work done?

The minimum amount of work must equal *KE*, or 8.8×10^6 J. The engine had to do more work than was dissipated in work done against friction.

c. What was the average acceleration of the automobile?

$$\bar{a} = \frac{\Delta v}{\Delta t}$$
$$= \frac{112\text{ m/s}}{9.8\text{ s}}$$
$$= 11\text{ m/s}^2$$

106. How much water would a steam engine have to evaporate in 1 s to produce 1 kW of power? Assume that the engine is 20 percent efficient. (Chapter 12)

$$\frac{W}{t} = 1000\text{ J/s}$$

If the engine is only 20 percent efficient it must use five times more heat to produce the 1000 J/s.

$$\frac{Q}{t} = 5000\text{ J/s} = \frac{mH_v}{t}$$

Therefore, $\frac{m}{t} = \frac{5000\text{ J/s}}{H_v}$

$$= \frac{5000\text{ J/s}}{2.26\times10^6\text{ J/kg}}$$
$$= 2\times10^{-3}\text{ kg/s}$$

Challenge Problem

page 380

A car of mass *m* rests at the top of a hill of height *h* before rolling without friction into a crash barrier located at the bottom of the hill. The crash barrier contains a spring with a spring constant, *k*, which is designed to bring the car to rest with minimum damage.

1. Determine, in terms of *m*, *h*, *k*, and *g*, the maximum distance, *x*, that the spring will be compressed when the car hits it.

Conservation of energy implies that the gravitational potential energy of the car at the top of the hill will be equal to the elastic potential energy in the spring when it has brought the car to rest. The equations for these energies can be set equal and solved for *x*.

$PE_g = PE_{sp}$, so $mgh = \frac{1}{2}kx^2$

$$x = \sqrt{\frac{2mgh}{k}}$$

2. If the car rolls down a hill that is twice as high, how much farther will the spring be compressed?

   The height is doubled and *x* is proportional to the square root of the height, so *x* will increase by $\sqrt{2}$.

3. What will happen after the car has been brought to rest?

   In the case of an ideal spring, the spring will propel the car back to the top of the hill.