Chapter 11: Oscillations and Waves

Questions

1. Is the acceleration of a simple harmonic oscillator ever zero? If so, where?
2. Real springs have mass. Will the true period and frequency be larger or smaller than given by the equations for a mass oscillating on the end of an idealized massless spring? Explain.
3. How could you double the maximum speed of a simple harmonic oscillator (SHO)?
4. If a pendulum clock is accurate at sea level, will it gain or lose time when taken to high altitude? Why?
5. A tire swing hanging from a branch reaches nearly to the ground (Fig. 11–49). How could you estimate the height of the branch using only a stopwatch?
6. For a simple harmonic oscillator, when (if ever) are the displacement and velocity vectors in the same direction? When are the displacement and acceleration vectors in the same direction?
7. Two equal masses are attached to separate identical springs next to one another. One mass is pulled so its spring stretches 40 cm and the other is pulled so its spring stretches only 20 cm. The masses are released simultaneously. Which mass reaches the equilibrium point first?
8. What is the approximate period of your walking step?
9. What happens to the period of a playground swing if you rise up from sitting to a standing position?
10. Why can you make water slosh back and forth in a pan only if you shake the pan at a certain frequency?
11. Is the frequency of a simple periodic wave equal to the frequency of its source? Why or why not?
12. Explain the difference between the speed of a transverse wave traveling along a cord and the speed of a tiny piece of the cord.
13. What kind of waves do you think will travel along a horizontal metal rod if you strike its end (a) vertically from above and (b) horizontally parallel to its length?
14. Since the density of air decreases with an increase in temperature, but the bulk modulus $B$ is nearly independent of temperature, how would you expect the speed of sound waves in air to vary with temperature?
15. If a rope has a free end, a pulse sent down the rope behaves differently on reflection than if the rope has that end fixed in position. What is this difference, and why does it occur?
16. How did geophysicists determine that part of the Earth’s interior is liquid?
17. The speed of sound in most solids is somewhat greater than in air, yet the density of solids is much greater ($10^3$ to $10^4$ times). Explain.
18. Give two reasons why circular water waves decrease in amplitude as they travel away from the source.
19. Two linear waves have the same amplitude and speed, and otherwise are identical, except one has half the wavelength of the other. Which transmits more energy? By what factor?
20. When a sinusoidal wave crosses the boundary between two sections of cord as in Fig. 11–34, the frequency does not change (although the wavelength and velocity do change). Explain why.
22. If a string is vibrating as a standing wave in three loops, are there any places you could touch it with a knife blade without disturbing the motion?
23. Why do the strings used for the lowest-frequency notes on a piano normally have wire wrapped around them?

24. When a standing wave exists on a string, the vibrations of incident and reflected waves cancel at the nodes. Does this mean that energy was destroyed? Explain.

25. Can the amplitude of the standing waves in Fig. 11–40 be greater than the amplitude of the vibrations that cause them (up and down motion of the hand)?

26. “In a round bowl of water, waves move from the center to the rim, or from the rim to the center, depending on whether you strike at the center or at the rim.” So wrote Dante Alighieri 700 years ago in his great poem *Paradiso* (Canto 14), the last part of his famous *Divine Comedy*. Try this experiment and discuss your results.

*27. AM radio signals can usually be heard behind a hill, but FM often cannot. That is, AM signals bend more than FM. Explain. (Radio signals, as we shall see, are carried by electromagnetic waves whose wavelength for AM is typically 200 to 600 m and for FM about 3 m.)*

**MisConceptual Questions**

1. A mass on a spring in SHM (Fig. 11–1) has amplitude $A$ and period $T$. At what point in the motion is the velocity zero and the acceleration zero simultaneously?
   
   (a) $x = A.$

   (b) $x > 0$ but $x < A.$

   (c) $x = 0.$

   (d) $x < 0.$

   (e) None of the above.

2. An object oscillates back and forth on the end of a spring. Which of the following statements are true at some time during the course of the motion?

   (a) The object can have zero velocity and, simultaneously, nonzero acceleration.

   (b) The object can have zero velocity and, simultaneously, zero acceleration.

   (c) The object can have zero acceleration and, simultaneously, nonzero velocity.

   (d) The object can have nonzero velocity and nonzero acceleration simultaneously.

3. An object of mass $M$ oscillates on the end of a spring. To double the period, replace the object with one of mass:

   (a) $2M.$

   (b) $M/2.$

   (c) $4M.$

   (d) $M/4.$

   (e) None of the above.

4. An object of mass $m$ rests on a frictionless surface and is attached to a horizontal ideal spring with spring constant $k$. The system oscillates with amplitude $A$. The oscillation frequency of this system can be increased by

   (a) decreasing $k$.

   (b) decreasing $m$.

   (c) increasing $A$. 

Copyright © 2014 Pearson Education, Inc.
5. When you use the approximation \( \sin \theta \approx \theta \) for a pendulum, you must specify the angle \( \theta \) in
   (a) radians only.
   (b) degrees only.
   (c) revolutions or radians.
   (d) degrees or radians.

6. Suppose you pull a simple pendulum to one side by an angle of 5°, let go, and measure the period of oscillation that ensues. Then you stop the oscillation, pull the pendulum to an angle of 10°, and let go. The resulting oscillation will have a period about __________ the period of the first oscillation.
   (a) four times
   (b) twice
   (c) half
   (d) one-fourth
   (e) the same as

7. At a playground, two young children are on identical swings. One child appears to be about twice as heavy as the other. If you pull them back together the same distance and release them to start them swinging, what will you notice about the oscillations of the two children?
   (a) The heavier child swings with a period twice that of the lighter one.
   (b) The lighter child swings with a period twice that of the heavier one.
   (c) Both children swing with the same period.

8. A grandfather clock is “losing” time because its pendulum moves too slowly. Assume that the pendulum is a massive bob at the end of a string. The motion of this pendulum can be sped up by (list all that work):
   (a) shortening the string.
   (b) lengthening the string.
   (c) increasing the mass of the bob.
   (d) decreasing the mass of the bob.

9. Consider a wave traveling down a cord and the transverse motion of a small piece of the cord. Which of the following is true?
   (a) The speed of the wave must be the same as the speed of a small piece of the cord.
   (b) The frequency of the wave must be the same as the frequency of a small piece of the cord.
   (c) The amplitude of the wave must be the same as the amplitude of a small piece of the cord.
   (d) All of the above are true.
   (e) Both (b) and (c) are true.

10. Two waves are traveling toward each other along a rope. When they meet, the waves
    (a) pass through each other.
    (b) bounce off of each other.
    (c) disappear.
11. Which of the following increases the speed of waves in a stretched elastic cord? (More than one answer may apply.)

(a) Increasing the wave amplitude.
(b) Increasing the wave frequency.
(c) Increasing the wavelength.
(d) Stretching the elastic cord further.

12. Consider a wave on a string moving to the right, as shown in Fig. 11–50. What is the direction of the velocity of a particle of string at point B?

(a) [Insert img]
(b) [Insert img]
(c) [Insert img]
(d) [Insert img]
(e) \( \vec{v} = 0 \), so no direction.

13. What happens when two waves, such as waves on a lake, come from different directions and run into each other?

(a) They cancel each other out and disappear.
(b) If they are the same size, they cancel each other out and disappear. If one wave is larger than the other, the smaller one disappears and the larger one shrinks but continues.
(c) They get larger where they run into each other; then they continue in a direction between the direction of the two original waves and larger than either original wave.
(d) They may have various patterns where they overlap, but each wave continues with its original pattern away from the region of overlap.
(e) Waves cannot run into each other; they always come from the same direction and so are parallel.

14. A student attaches one end of a Slinky to the top of a table. She holds the other end in her hand, stretches it to a length \( l \), and then moves it back and forth to send a wave down the Slinky. If she next moves her hand faster while keeping the length of the Slinky the same, how does the wavelength down the Slinky change?

(a) It increases.
(b) It stays the same.
(c) It decreases.

15. A wave transports

(a) energy but not matter.
(b) matter but not energy.
(c) both energy and matter.

Problems

11–1 to 11–3 Simple Harmonic Motion

1. If a particle undergoes SHM with amplitude 0.21 m, what is the total distance it travels in one period?
2. (I) The springs of a 1700-kg car compress 5.0 mm when its 66-kg driver gets into the driver’s seat. If the car goes over a bump, what will be the frequency of oscillations? Ignore damping.

3. (II) An elastic cord is 61 cm long when a weight of 75 N hangs from it but is 85 cm long when a weight of 210 N hangs from it. What is the “spring” constant \( k \) of this elastic cord?

4. (II) Estimate the stiffness of the spring in a child’s pogo stick if the child has a mass of 32 kg and bounces once every 2.0 seconds.

5. (II) A fisherman’s scale stretches 3.6 cm when a 2.4-kg fish hangs from it. (a) What is the spring stiffness constant and (b) what will be the amplitude and frequency of oscillation if the fish is pulled down 2.1 cm more and released so that it oscillates up and down?

6. (II) A small fly of mass 0.22 g is caught in a spider’s web. The web oscillates predominantly with a frequency of 4.0 Hz. (a) What is the value of the effective spring stiffness constant \( k \) for the web? (b) At what frequency would you expect the web to oscillate if an insect of mass 0.44 g were trapped?

7. (II) A mass \( m \) at the end of a spring oscillates with a frequency of 0.83 Hz. When an additional 780-g mass is added to \( m \), the frequency is 0.60 Hz. What is the value of \( m \)?

8. (II) A vertical spring with spring stiffness constant 305 N/m oscillates with an amplitude of 28.0 cm when 0.235 kg hangs from it. The mass passes through the equilibrium point (\( y = 0 \)) with positive velocity at \( t = 0 \). (a) What equation describes this motion as a function of time? (b) At what times will the spring be longest and shortest?

9. (II) Figure 11–51 shows two examples of SHM, labeled A and B. For each, what is (a) the amplitude, (b) the frequency, and (c) the period?

10. (II) A balsa wood block of mass 52 g floats on a lake, bobbing up and down at a frequency of 3.0 Hz. (a) What is the value of the effective spring constant of the water? (b) A partially filled water bottle of mass 0.28 kg and almost the same size and shape of the balsa block is tossed into the water. At what frequency would you expect the bottle to bob up and down? Assume SHM.

11. (II) At what displacement of a SHO is the energy half kinetic and half potential?

12. (II) An object of unknown mass \( m \) is hung from a vertical spring of unknown spring constant \( k \), and the object is observed to be at rest when the spring has stretched by 14 cm. The object is then given a slight push upward and executes SHM. Determine the period \( T \) of this oscillation.

13. (II) A 1.65-kg mass stretches a vertical spring 0.215 m. If the spring is stretched an additional 0.130 m and released, how long does it take to reach the (new) equilibrium position again?

14. (II) A 1.15-kg mass oscillates according to the equation \( x = 0.650 \cos(8.40t) \) where \( x \) is in meters and \( t \) in seconds. Determine (a) the amplitude, (b) the frequency, (c) the total energy, and (d) the kinetic energy and potential energy when \( x = 0.360 \) m.

15. (II) A 0.25-kg mass at the end of a spring oscillates 2.2 times per second with an amplitude of 0.15 m. Determine (a) the speed when it passes the equilibrium point, (b) the speed when it is 0.10 m from equilibrium, (c) the total energy of the system, and (d) the equation describing the motion of the mass, assuming that at \( t = 0 \), \( x \) was a maximum.

16. (II) It takes a force of 91.0 N to compress the spring of a toy popgun 0.175 m to “load” a 0.160-kg ball. With what speed will the ball leave the gun if fired horizontally?
17. (II) If one oscillation has 3.0 times the energy of a second one of equal frequency and mass, what is the ratio of their amplitudes?

18. (II) A mass of 240 g oscillates on a horizontal frictionless surface at a frequency of 2.5 Hz and with amplitude of 4.5 cm.
   (a) What is the effective spring constant for this motion? (b) How much energy is involved in this motion?

19. (II) A mass resting on a horizontal, frictionless surface is attached to one end of a spring; the other end is fixed to a wall. It takes 3.6 J of work to compress the spring by 0.13 m. If the spring is compressed, and the mass is released from rest, it experiences a maximum acceleration of 12 m/s². Find the value of (a) the spring constant and (b) the mass.

20. (II) An object with mass 2.7 kg is executing simple harmonic motion, attached to a spring with spring constant \( k = 310 \) N/m. When the object is 0.020 m from its equilibrium position, it is moving with a speed of 0.55 m/s. (a) Calculate the amplitude of the motion. (b) Calculate the maximum speed attained by the object.

21. (II) At \( t = 0 \), an 885-g mass at rest on the end of a horizontal spring \( (k = 184 \) N/m) is struck by a hammer which gives it an initial speed of 2.26 m/s. Determine (a) the period and frequency of the motion, (b) the amplitude, (c) the maximum acceleration, (d) the total energy, and (e) the kinetic energy when \( x = 0.40A \) where \( A \) is the amplitude.

22. (III) Agent Arlene devised the following method of measuring the muzzle velocity of a rifle (Fig. 11–52). She fires a bullet into a 4.148-kg wooden block resting on a smooth surface, and attached to a spring of spring constant \( k = 162.7 \) N/m. The bullet, whose mass is 7.870 g, remains embedded in the wooden block. She measures the maximum distance that the block compresses the spring to be 9.460 cm. What is the speed \( v \) of the bullet?

23. (III) A bungee jumper with mass 65.0 kg jumps from a high bridge. After arriving at his lowest point, he oscillates up and down, reaching a low point seven more times in 43.0 s. He finally comes to rest 25.0 m below the level of the bridge. Estimate the spring stiffness constant and the unstretched length of the bungee cord assuming SHM.

24. (III) A block of mass \( m \) is supported by two identical parallel vertical springs, each with spring stiffness constant \( k \) (Fig. 11–53). What will be the frequency of vertical oscillation?

25. (III) A 1.60-kg object oscillates at the end of a vertically hanging light spring once every 0.45 s. (a) Write down the equation giving its position \( y \) (+ upward) as a function of time \( t \). Assume the object started by being compressed 16 cm from the equilibrium position (where \( y = 0 \)), and released. (b) How long will it take to get to the equilibrium position for the first time? (c) What will be its maximum speed? (d) What will be the object’s maximum acceleration, and where will it first be attained?

26. (III) Consider two objects, A and B, both undergoing SHM, but with different frequencies, as described by the equations \( x_A = (2.0 \) m \) sin(4.0 \( \) t) and \( x_B = (5.0 \) m \) sin(3.0 \( \) t), where \( t \) is in seconds. After \( t = 0 \), find the next three times \( t \) at which both objects simultaneously pass through the origin.

11–4 Simple Pendulum

27. (I) A pendulum has a period of 1.85 s on Earth. What is its period on Mars, where the acceleration of gravity is about 0.37 that on Earth?

28. (I) How long must a simple pendulum be if it is to make exactly one swing per second? (That is, one complete oscillation takes exactly 2.0 s.)

29. (I) A pendulum makes 28 oscillations in exactly 50 s. What is its (a) period and (b) frequency?

30. (II) What is the period of a simple pendulum 47 cm long (a) on the Earth, and (b) when it is in a freely falling elevator?
31. (II) Your grandfather clock’s pendulum has a length of 0.9930 m. If the clock runs slow and loses 21 s per day, how should you adjust the length of the pendulum?

32. (II) Derive a formula for the maximum speed $v_{\text{max}}$ of a simple pendulum bob in terms of $g$, the length $\ell$, and the maximum angle of swing $\theta_{\text{max}}$.

33. (III) A simple pendulum oscillates with an amplitude of 10.0°. What fraction of the time does it spend between +5.0° and −5.0°? Assume SHM.

34. (III) A clock pendulum oscillates at a frequency of 2.5 Hz. At $t = 0$, it is released from rest starting at an angle of 12° to the vertical. Ignoring friction, what will be the position (angle in radians) of the pendulum at (a) $t = 0.25$ s, (b) $t = 1.60$ s, and (c) $t = 500$ s?

11–7 and 11–8 Waves

35. (I) A fisherman notices that wave crests pass the bow of his anchored boat every 3.0 s. He measures the distance between two crests to be 7.0 m. How fast are the waves traveling?

36. (I) A sound wave in air has a frequency of 282 Hz and travels with a speed of 343 m/s. How far apart are the wave crests (compressions)?

37. (I) Calculate the speed of longitudinal waves in (a) water, (b) granite, and (c) steel.

38. (I) AM radio signals have frequencies between 550 kHz and 1600 kHz (kilohertz) and travel with a speed of $3.0 \times 10^8$ m/s. What are the wavelengths of these signals? On FM the frequencies range from 88 MHz to 108 MHz (megahertz) and travel at the same speed. What are their wavelengths?

39. (II) P and S waves from an earthquake travel at different speeds, and this difference helps locate the earthquake “epicenter” (where the disturbance took place). (a) Assuming typical speeds of 8.5 km/s and 5.5 km/s for P and S waves, respectively, how far away did an earthquake occur if a particular seismic station detects the arrival of these two types of waves 1.5 min apart? (b) Is one seismic station sufficient to determine the position of the epicenter? Explain.

40. (II) A cord of mass 0.65 kg is stretched between two supports 8.0 m apart. If the tension in the cord is 120 N, how long will it take a pulse to travel from one support to the other?

41. (II) A 0.40-kg cord is stretched between two supports, 8.7 m apart. When one support is struck by a hammer, a transverse wave travels down the cord and reaches the other support in 0.85 s. What is the tension in the cord?

42. (II) A sailor strikes the side of his ship just below the surface of the sea. He hears the echo of the wave reflected from the ocean floor directly below 2.4 s later. How deep is the ocean at this point?

43. (II) Two children are sending signals along a cord of total mass 0.50 kg tied between tin cans with a tension of 35 N. It takes the vibrations in the string 0.55 s to go from one child to the other. How far apart are the children?

11–9 Energy Transported by Waves

44. (II) What is the ratio of (a) the intensities, and (b) the amplitudes, of an earthquake P wave passing through the Earth and detected at two points 15 km and 45 km from the source?

45. (II) The intensity of an earthquake wave passing through the Earth is measured to be $3.0 \times 10^6$ J/m² • s at a distance of 54 km from the source. (a) What was its intensity when it passed a point only 1.0 km from the source? (b) At what rate did energy pass through an area of 2.0 m² at 1.0 km?
46. (II) A bug on the surface of a pond is observed to move up and down a total vertical distance of 7.0 cm, from the lowest to the highest point, as a wave passes. If the ripples decrease to 4.5 cm, by what factor does the bug’s maximum KE change?

47. (II) Two earthquake waves of the same frequency travel through the same portion of the Earth, but one is carrying 5.0 times the energy. What is the ratio of the amplitudes of the two waves?

11–11 Interference

48. (I) The two pulses shown in Fig. 11–54 are moving toward each other. (a) Sketch the shape of the string at the moment they directly overlap. (b) Sketch the shape of the string a few moments later. (c) In Fig. 11–37a, at the moment the pulses pass each other, the string is straight. What has happened to the energy at this moment?

11–12 Standing Waves; Resonance

49. (I) If a violin string vibrates at 440 Hz as its fundamental frequency, what are the frequencies of the first four harmonics?

50. (I) A violin string vibrates at 294 Hz when unfingered. At what frequency will it vibrate if it is fingered one-third of the way down from the end? (That is, only two-thirds of the string vibrates as a standing wave.)

51. (I) A particular string resonates in four loops at a frequency of 240 Hz. Give at least three other frequencies at which it will resonate. What is each called?

52. (II) The speed of waves on a string is 97 m/s. If the frequency of standing waves is 475 Hz, how far apart are two adjacent nodes?

53. (II) If two successive overtones of a vibrating string are 280 Hz and 350 Hz, what is the frequency of the fundamental?

54. (II) A guitar string is 92 cm long and has a mass of 3.4 g. The distance from the bridge to the support post is \( \ell = 62 \) cm, and the string is under a tension of 520 N. What are the frequencies of the fundamental and first two overtones?

55. (II) One end of a horizontal string is attached to a small-amplitude mechanical 60.0-Hz oscillator. The string’s mass per unit length is \( 3.5 \times 10^{-4} \) kg/m. The string passes over a pulley, a distance \( \ell = 1.50 \) m away, and weights are hung from this end, Fig. 11–55. What mass \( m \) must be hung from this end of the string to produce (a) one loop, (b) two loops, and (c) five loops of a standing wave? Assume the string at the oscillator is a node, which is nearly true.

56. (II) In Problem 55 (Fig. 11–55), the length \( \ell \) of the string may be adjusted by moving the pulley. If the hanging mass \( m \) is fixed at 0.080 kg, how many different standing wave patterns may be achieved by varying \( \ell \) between 10 cm and 1.5 m?

57. (II) When you slosh the water back and forth in a tub at just the right frequency, the water alternately rises and falls at each end, remaining relatively calm at the center. Suppose the frequency to produce such a standing wave in a 75-cm-wide tub is 0.85 Hz. What is the speed of the water wave?

*11–13 Refraction

*58. (I) An earthquake P wave traveling at 8.0 km/s strikes a boundary within the Earth between two kinds of material. If it approaches the boundary at an incident angle of 44° and the angle of refraction is 33°, what is the speed in the second medium?
*59. (II) A sound wave is traveling in warm air when it hits a layer of cold, dense air. If the sound wave hits the cold air interface at an angle of 25°, what is the angle of refraction? Assume that the cold air temperature is –15°C and the warm air temperature is +15°C. The speed of sound as a function of temperature can be approximated by \( v = (331 + 0.60T) \text{ m/s}, \) where \( T \) is in °C.

*60. (III) A longitudinal earthquake wave strikes a boundary between two types of rock at a 38° angle. As the wave crosses the boundary, the specific gravity changes from 3.6 to 2.5. Assuming that the elastic modulus is the same for both types of rock, determine the angle of refraction.

**11–14 Diffraction**

*61. (II) What frequency of sound would have a wavelength the same size as a 0.75-m-wide window? (The speed of sound is 344 m/s at 20°C.) What frequencies would diffract through the window?

**General Problems**

62. A 62-kg person jumps from a window to a fire net 20.0 m directly below, which stretches the net 1.4 m. Assume that the net behaves like a simple spring. (a) Calculate how much it would stretch if the same person were lying in it. (b) How much would it stretch if the person jumped from 38 m?

63. An energy-absorbing car bumper has a spring constant of 410 kN/m. Find the maximum compression of the bumper if the car, with mass 1300 kg, collides with a wall at a speed of 2.0 m/s (approximately 5 mi/h).

64. The length of a simple pendulum is 0.72 m, the pendulum bob has a mass of 295 g, and it is released at an angle of 12° to the vertical. Assume SHM. (a) With what frequency does it oscillate? (b) What is the pendulum bob’s speed when it passes through the lowest point of the swing? (c) What is the total energy stored in this oscillation assuming no losses?

65. A block of mass \( M \) is suspended from a ceiling by a spring with spring stiffness constant \( k. \) A penny of mass \( m \) is placed on top of the block. What is the maximum amplitude of oscillations that will allow the penny to just stay on top of the block? (Assume \( m = M. \))

66. A block with mass \( M = 6.0 \text{ kg} \) rests on a frictionless table and is attached by a horizontal spring (\( k = 130 \text{ N/m} \)) to a wall. A second block, of mass \( m = 1.25 \text{ kg} \), rests on top of \( M. \) The coefficient of static friction between the two blocks is 0.30. What is the maximum possible amplitude of oscillation such that \( m \) will not slip off \( M? \)

67. A simple pendulum oscillates with frequency \( f. \) What is its frequency if the entire pendulum accelerates at 0.35 \( g \) (a) upward, and (b) downward?

68. A 0.650-kg mass oscillates according to the equation \( x = 0.25 \sin(4.70 \, t) \) where \( x \) is in meters and \( t \) is in seconds. Determine (a) the amplitude, (b) the frequency, (c) the period, (d) the total energy, and (e) the kinetic energy and potential energy when \( x \) is 15 cm.

69. An oxygen atom at a particular site within a DNA molecule can be made to execute simple harmonic motion when illuminated by infrared light. The oxygen atom is bound with a spring-like chemical bond to a phosphorus atom, which is rigidly attached to the DNA backbone. The oscillation of the oxygen atom occurs with frequency \( f = 3.7 \times 10^{13} \text{ Hz}. \) If the oxygen atom at this site is chemically replaced with a sulfur atom, the spring constant of the bond is unchanged (sulfur is just below oxygen in the Periodic Table). Predict the frequency after the sulfur substitution.
70. A rectangular block of wood floats in a calm lake. Show that, if friction is ignored, when the block is pushed gently down into the water and then released, it will then oscillate with SHM. Also, determine an equation for the force constant.

71. A 320-kg wooden raft floats on a lake. When a 68-kg man stands on the raft, it sinks 3.5 cm deeper into the water. When he steps off, the raft oscillates for a while. (a) What is the frequency of oscillation? (b) What is the total energy of oscillation (ignoring damping)?

72. A diving board oscillates with simple harmonic motion of frequency 2.8 cycles per second. What is the maximum amplitude with which the end of the board can oscillate in order that a pebble placed there (Fig. 11–56) does not lose contact with the board during the oscillation?

73. A 950-kg car strikes a huge spring at a speed of 25 m/s (Fig. 11–57), compressing the spring 4.0 m. (a) What is the spring stiffness constant of the spring? (b) How long is the car in contact with the spring before it bounces off in the opposite direction?

74. A mass attached to the end of a spring is stretched a distance $x_0$ from equilibrium and released. At what distance from equilibrium will it have (a) velocity equal to half its maximum velocity, and (b) acceleration equal to half its maximum acceleration?

75. Carbon dioxide is a linear molecule. The carbon-oxygen bonds in this molecule act very much like springs. Figure 11–58 shows one possible way the oxygen atoms in this molecule can oscillate: the oxygen atoms oscillate symmetrically in and out, while the central carbon atom remains at rest. Hence each oxygen atom acts like a simple harmonic oscillator with a mass equal to the mass of an oxygen atom. It is observed that this oscillation occurs at a frequency $f = 2.83 \times 10^{13}$ Hz. What is the spring constant of the C — O bond?

76. A mass $m$ is gently placed on the end of a freely hanging spring. The mass then falls 27.0 cm before it stops and begins to rise. What is the frequency of the oscillation?

77. Tall buildings are designed to sway in the wind. In a 100-km/h wind, suppose the top of a 110-story building oscillates horizontally with an amplitude of 15 cm at its natural frequency, which corresponds to a period of 7.0 s. Assuming SHM, find the maximum horizontal velocity and acceleration experienced by an employee as she sits working at her desk located on the top floor. Compare the maximum acceleration (as a percentage) with the acceleration due to gravity.

78. When you walk with a cup of coffee (diameter 8 cm) at just the right pace of about one step per second, the coffee sloshes higher and higher in your cup until eventually it starts to spill over the top, Fig 11–59. Estimate the speed of the waves in the coffee.

79. A bug on the surface of a pond is observed to move up and down a total vertical distance of 0.12 m, lowest to highest point, as a wave passes. (a) What is the amplitude of the wave? (b) If the amplitude increases to 0.16 m, by what factor does the bug’s maximum kinetic energy change?

80. An earthquake-produced surface wave can be approximated by a sinusoidal transverse wave. Assuming a frequency of 0.60 Hz (typical of earthquakes, which actually include a mixture of frequencies), what amplitude is needed so that objects begin to leave contact with the ground? [Hint: Set the acceleration $a > g$.]

81. Two strings on a musical instrument are tuned to play at 392 Hz (G) and 494 Hz (B). (a) What are the frequencies of the first two overtones for each string? (b) If the two strings have the same length and are under the same tension, what must be the ratio of their masses ($m_G/m_B$)? (c) If the strings, instead, have the same mass per unit length and are under the same
tension, what is the ratio of their lengths ($\ell_G/\ell_B$)? (d) If their masses and lengths are the same, what must be the ratio of the tensions in the two strings?

82. A string can have a “free” end if that end is attached to a ring that can slide without friction on a vertical pole (Fig. 11–60). Determine the wavelengths of the resonant vibrations of such a string with one end fixed and the other free.

83. The ripples in a certain groove 10.2 cm from the center of a $33\frac{1}{2}$-rpm phonograph record have a wavelength of 1.55 mm. What will be the frequency of the sound emitted?

84. A wave with a frequency of 180 Hz and a wavelength of 10.0 cm is traveling along a cord. The maximum speed of particles on the cord is the same as the wave speed. What is the amplitude of the wave?

85. Estimate the average power of a moving water wave that strikes the chest of an adult standing in the water at the seashore. Assume that the amplitude of the wave is 0.50 m, the wavelength is 2.5 m, and the period is 4.0 s.

86. A tsunami is a sort of pulse or “wave packet” consisting of several crests and troughs that become dramatically large as they enter shallow water at the shore. Suppose a tsunami of wavelength 235 km and velocity 550 km/h travels across the Pacific Ocean. As it approaches Hawaii, people observe an unusual decrease of sea level in the harbors. Approximately how much time do they have to run to safety? (In the absence of knowledge and warning, people have died during tsunamis, some of them attracted to the shore to see stranded fishes and boats.)

*87. For any type of wave that reaches a boundary beyond which its speed is increased, there is a maximum incident angle if there is to be a transmitted refracted wave. This maximum incident angle $\theta_M$ corresponds to an angle of refraction equal to 90°. If $\theta > \theta_M$, all the wave is reflected at the boundary and none is refracted, because refraction would correspond to $\sin \theta > 1$ (where $\theta$ is the angle of refraction), which is impossible. This phenomenon is referred to as total internal reflection. (a) Find a formula for $\theta_M$ using the law of refraction, Eq. 11–20. (b) How far from the bank should a trout fisherman stand (Fig. 11–61) so trout won’t be frightened by his voice (1.8 m above the ground)? The speed of sound is about 343 m/s in air and 1440 m/s in water.

Search and Learn

1. Describe a procedure to measure the spring constant $k$ of a car’s springs. Assume that the owner’s manual gives the car’s mass $M$ and that the shock absorbers are worn out so that the springs are underdamped. (See Sections 11–3 and 11–5.)

2. A particular unbalanced wheel of a car shakes when the car moves at 90.0 km/h. The wheel plus tire has mass 17.0 kg and diameter 0.58 m. By how much will the springs of this car compress when it is loaded with 280 kg? (Assume the 280 kg is split evenly among all four springs, which are identical.) [Hint: Reread Sections 11–1, 11–3, 11–6, and 8–3.]

3. Sometimes a car develops a pronounced rattle or vibration at a particular speed, especially if the road is hot enough that the tar between concrete slabs bumps up at regularly spaced intervals. Reread Sections 11–5 and 11–6, and decide whether each of the following is a factor and, if so, how: underdamping, overdamping, critical damping, and forced resonance.

4. Destructive interference occurs where two overlapping waves are $\frac{1}{2}$ wavelength or 180° out of phase. Explain why 180° is equivalent to $\frac{1}{2}$ wavelength.

5. Estimate the effective spring constant of a trampoline. [Hint: Go and jump, or watch, and give your data.]
6. A highway overpass was observed to resonate as one full loop \( \frac{1}{2} \lambda \) when a small earthquake shook the ground vertically at 3.0 Hz. The highway department put a support at the center of the overpass, anchoring it to the ground as shown in Fig. 11–62. What resonant frequency would you now expect for the overpass? It is noted that earthquakes rarely do significant shaking above 5 or 6 Hz. Did the modifications do any good? Explain. (See Section 11–3.)