Problems

11–1 to 11–3 Simple Harmonic Motion

1. (I) If a particle undergoes SHM with amplitude 0.18 m, what is the total distance it travels in one period?

2. (I) An elastic cord is 65 cm long when a weight of 75 N hangs from it but is 85 cm long when a weight of 180 N hangs from it. What is the "spring" constant k of this elastic cord?

3. (I) The springs of a 1500-kg car compress 5.0 mm when its 68-kg driver gets into the driver's seat. If the car goes over a bump, what will be the frequency of vibrations?

4. (II) A fisherman's scale stretches 3.6 cm when a 2.7-kg fish hangs from it. (*a*) What is the spring stiffness constant and (*b*) what will be the amplitude and frequency of vibration if the fish is pulled down 2.5 cm more and released so that it vibrates up and down?

5. (II) An elastic cord vibrates with a frequency of 3.0 Hz when a mass of 0.60 kg is hung from it. What is its frequency if only 0.38 kg hangs from it?

6. (II) Construct a Table indicating the position x of the mass in Fig. 11–2 at times $t = 0, \frac{1}{4}T, \frac{1}{2}T, \frac{3}{4}T, T,$ and $\frac{5}{4}T$, where T is the period of oscillation. On a graph of x vs. t, plot these six points. Now connect these points with a smooth curve. Based on these simple considerations, does your curve resemble that of a cosine or sine wave (Fig. 11–8a or 11–9)?

7. (II) A small fly of mass 0.25 g is caught in a spider's web. The web vibrates predominately 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 vibrate if an insect of mass 0.50 g were trapped?

8. (II) A mass m at the end of a spring vibrates with a frequency of 0.88 Hz. When an additional 680-g mass is added to m, the frequency is 0.60 Hz. What is the value of m?

9. (II) A 0.60-kg mass at the end of a spring vibrates 3.0 times per second with an amplitude of 0.13 m. Determine (*a*) the velocity when it passes the equilibrium point, (*b*) the velocity 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 x was a maximum at $t = 0$.

10. (II) At what displacement from equilibrium is the speed of a SHO half the maximum value?

11. (II) 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 acceleration equal to half its maximum acceleration?

12. (II) A mass of 2.62 kg stretches a vertical spring 0.315 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?

13. (II) An object with mass 3.0 kg is attached to a spring with spring stiffness constant $k = 280\ \text{N/m}$ and is executing simple harmonic motion. 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 velocity attained by the object. [*Hint*: Use conservation of energy.]

14. (II) It takes a force of 80.0 N to compress the spring of a toy popgun 0.200 m to "load" a 0.180-kg ball. With what speed will the ball leave the gun?

15. (II) A mass sitting on a horizontal, frictionless surface is attached to one end of a spring; the other end is fixed to a wall. 3.0 J of work is required to compress the spring by 0.12 m. If the mass is released from rest with the spring compressed, the mass experiences a maximum acceleration of 15 m/s^2. Find the value of (*a*) the spring stiffness constant and (*b*) the mass.

16. (II) A 0.60-kg mass vibrates according to the equation $x = 0.45 \cos 6.40t$, where x is in meters and t is in seconds. Determine (*a*) the amplitude, (*b*) the frequency, (*c*) the total energy, and (*d*) the kinetic energy and potential energies when $x = 0.30$ m.

17. (II) At what displacement from equilibrium is the energy of a SHO half KE and half PE?

18. (II) If one vibration has 7.0 times the energy of a second, but their frequencies and masses are the same, what is the ratio of their amplitudes?

19. (II) A 2.00-kg pumpkin oscillates from a vertically hanging light spring once every 0.65 s. (*a*) Write down the equation giving the pumpkin's position y (+ upward) as a function of time t, assuming it started by being compressed 18 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 the pumpkin's maximum speed? (*d*) What will be its maximum acceleration, and where will that first be attained?

20. (II) A block of mass m is supported by two identical parallel vertical springs, each with spring stiffness constant k (Fig. 11–49). What will be the frequency of vibration?

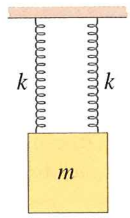

FIGURE 11–49 Problem 20.

21. (II) A 300-g mass vibrates according to the equation $x = 0.38 \sin 6.50t$, 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 KE and PE when x is 9.0 cm. (*f*) Draw a careful graph of x vs. t showing the correct amplitude and period.

22. (II) Figure 11–50 shows two examples of SHM, labeled A and B. For each, what is (*a*) the amplitude, (*b*) the frequency, and (*c*) the period? (*d*) Write the equations for both A and B in the form of a sine or cosine.

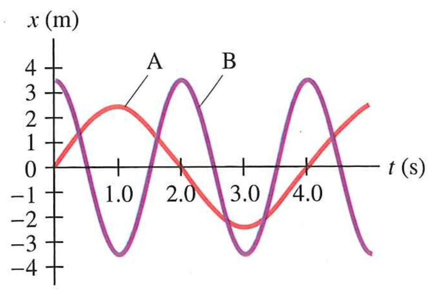

FIGURE 11–50 Problem 22.

23. (II) At $t = 0$, a 755-g mass at rest on the end of a horizontal spring ($k = 124\,\text{N/m}$) is struck by a hammer, which gives the mass an initial speed of 2.96 m/s. Determine (*a*) the period and frequency of the motion, (*b*) the amplitude, (*c*) the maximum acceleration, (*d*) the position as a function of time, and (*e*) the total energy.

24. (II) A vertical spring with spring stiffness constant 305 N/m vibrates with an amplitude of 28.0 cm when 0.260 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 have its maximum and minimum extensions?

25. (II) A mass m is connected to two springs, with spring stiffness constants k_1 and k_2, as shown in Fig. 11–51. Ignore friction. Show that the period is given by

$$T = 2\pi\sqrt{\frac{m}{k_1 + k_2}}.$$

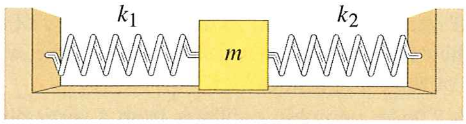

FIGURE 11–51 Problem 25.

26. (III) A 25.0-g bullet strikes a 0.600-kg block attached to a fixed horizontal spring whose spring stiffness constant is $7.70 \times 10^3\,\text{N/m}$. The block is set into vibration with an amplitude of 21.5 cm. What was the speed of the bullet before impact if the bullet and block move together after impact?

27. (III) A bungee jumper with mass 65.0 kg jumps from a high bridge. After reaching his lowest point, he oscillates up and down, hitting a low point eight more times in 38.0 s. He finally comes to rest 25.0 m below the level of the bridge. Calculate the spring stiffness constant and the unstretched length of the bungee cord.

11–4 Simple Pendulum

28. (I) A pendulum makes 36 vibrations in exactly 60 s. What is its (*a*) period, and (*b*) frequency?

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

30. (I) A pendulum has a period of 0.80 s on Earth. What is its period on Mars, where the acceleration of gravity is about 0.37 that on Earth?

31. (II) What is the period of a simple pendulum 80 cm long (*a*) on the Earth, and (*b*) when it is in a freely falling elevator?

32. (II) The length of a simple pendulum is 0.760 m, the pendulum bob has a mass of 365 grams, and it is released at an angle of 12.0° to the vertical. (*a*) With what frequency does it vibrate? Assume SHM. (*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?

33. (II) Your grandfather clock's pendulum has a length of 0.9930 m. If the clock loses half a minute per day, how should you adjust the length of the pendulum?

34. (II) Derive a formula for the maximum speed v_{max} of a simple pendulum bob in terms of g, the length L, and the angle of swing θ_0.

35. (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 15° to the vertical. Ignoring friction, what will be the position (angle) of the pendulum at (*a*) $t = 0.25$ s, (*b*) $t = 1.60$ s, and (*c*) $t = 500$ s? [*Hint*: Do not confuse the angle of swing θ of the pendulum with the angle that appears as the argument of the cosine.]

11–7 and 11–8 Waves

36. (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 6.5 m. How fast are the waves traveling?

37. (I) A sound wave in air has a frequency of 262 Hz and travels with a speed of 343 m/s. How far apart are the wave crests (compressions)?

38. (I) (*a*) AM radio signals have frequencies between 550 kHz and 1600 kHz (kilohertz) and travel with a speed of $3.00 \times 10^8\,\text{m/s}$. What are the wavelengths of these signals? (*b*) On FM, the frequencies range from 88.0 MHz to 108 MHz (megahertz) and travel at the same speed; what are their wavelengths?

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

* 40. (II) Two solid rods have the same elastic modulus, but one is twice as dense as the other. In which rod will the speed of longitudinal waves be greater, and by what factor?

41. (II) A cord of mass 0.65 kg is stretched between two supports 28 m apart. If the tension in the cord is 150 N, how long will it take a pulse to travel from one support to the other?

42. (II) A ski gondola is connected to the top of a hill by a steel cable of length 620 m and diameter 1.5 cm. As the gondola comes to the end of its run, it bumps into the terminal and sends a wave pulse along the cable. It is observed that it took 16 s for the pulse to return. (*a*) What is the speed of the pulse? (*b*) What is the tension in the cable?

* 43. (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 3.0 s later. How deep is the ocean at this point?

44. (II) P and S waves from an earthquake travel at different speeds, and this difference helps in locating 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 the earthquake occur if a particular seismic station detects the arrival of these two types of waves 2.0 min apart? (*b*) Is one seismic station sufficient to determine the position of the epicenter? Explain.

45. (III) An earthquake-produced surface wave can be approximated by a sinusoidal transverse wave. Assuming a frequency of 0.50 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 $a > g$.]

11–9 Wave Energy

46. (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 10 km and 20 km from the source.

47. (II) The intensity of an earthquake wave passing through the Earth is measured to be $2.0 \times 10^6\ \mathrm{J/m^2 \cdot s}$ at a distance of 48 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 $5.0\ \mathrm{m^2}$ at 1.0 km?

* 11–10 Intensity Related to A and f

* 48. (I) Two earthquake waves of the same frequency travel through the same portion of the Earth, but one is carrying twice the energy. What is the ratio of the amplitudes of the two waves?

* 49. (I) Two waves traveling along a stretched string have the same frequency, but one transports three times the power of the other. What is the ratio of the amplitudes of the two waves?

* 50. (II) A bug on the surface of a pond is observed to move up and down a total vertical distance of 6.0 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?

11–12 Interference

51. (I) The two pulses shown in Fig. 11–52 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. 11–36a, at the moment the pulses pass each other, the string is straight. What has happened to the energy at this moment?

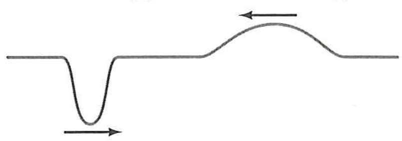

FIGURE 11–52 Problem 51.

11–13 Standing Waves; Resonance

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

53. (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.)

54. (I) A particular string resonates in four loops at a frequency of 280 Hz. Name at least three other frequencies at which it will resonate.

55. (II) The velocity of waves on a string is 92 m/s. If the frequency of standing waves is 475 Hz, how far apart are two adjacent nodes?

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

57. (II) A guitar string is 90 cm long and has a mass of 3.6 g. The distance from the bridge to the support post is $L = 62$ cm, and the string is under a tension of 520 N. What are the frequencies of the fundamental and first two overtones?

58. (II) A particular guitar string is supposed to vibrate at 200 Hz, but it is measured to vibrate at 205 Hz. By what percent should the tension in the string be changed to correct the frequency?

59. (II) One end of a horizontal string is attached to a small-amplitude mechanical 60-Hz vibrator. The string's mass per unit length is 3.9×10^{-4} kg/m. The string passes over a pulley, a distance $L = 1.50$ m away, and weights are hung from this end, Fig. 11–53. 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 vibrator is a node, which is nearly true.

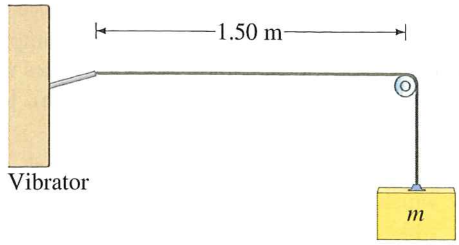

FIGURE 11–53 Problems 59 and 60.

60. (II) In Problem 59, the length 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 L between 10 cm and 1.5 m?

61. (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 65-cm-wide tub is 0.85 Hz. What is the speed of the water wave?

* 11–14 Refraction

* 62. (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 47° and the angle of refraction is 35°, what is the speed in the second medium?

* 63. (I) Water waves approach an underwater "shelf" where the velocity changes from 2.8 m/s to 2.1 m/s. If the incident wave crests make a 34° angle with the shelf, what will be the angle of refraction?

* 64. (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 −10°C and the warm air temperature is +10°C. The speed of sound as a function of temperature can be approximated by $v = (331 + 0.60\,T)$ m/s, where T is in °C.

* 65. (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 of the rock changes from 3.6 to 2.8. Assuming that the elastic modulus is the same for both types of rock, determine the angle of refraction.

* 11–15 Diffraction

* 66. (II) A satellite dish is about 0.5 m in diameter. According to the user's manual, the dish has to be pointed in the direction of the satellite, but an error of about 2° is allowed without loss of reception. Estimate the wavelength of the electromagnetic waves received by the dish.

General Problems

67. A tsunami of wavelength 250 km and velocity 750 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.)

68. An energy-absorbing car bumper has a spring stiffness constant of 550 kN/m. Find the maximum compression of the bumper if the car, with mass 1500 kg, collides with a wall at a speed of 2.2 m/s (approximately 5 mi/h). [*Hint*: Use conservation of energy.]

69. A 65-kg person jumps from a window to a fire net 18 m below, which stretches the net 1.1 m. Assume that the net behaves like a simple spring, and (*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 35 m?

70. A mass m is gently placed on the end of a freely hanging spring. The mass then falls 33 cm before it stops and begins to rise. What is the frequency of the oscillation?

71. A 950-kg car strikes a huge spring at a speed of 22 m/s (Fig. 11–54), compressing the spring 5.0 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?

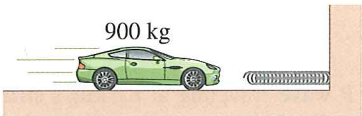

FIGURE 11–54 Problem 71.

72. When you walk with a cup of coffee (diameter 8 cm) at just the right pace of about 1 step per second, the coffee sloshes more and more until eventually it starts to spill over the top (Fig. 11–55). Estimate the speed of waves in the coffee.

FIGURE 11–55 Problem 72.

73. The ripples in a certain groove 10.8 cm from the center of a 33-rpm phonograph record have a wavelength of 1.70 mm. What will be the frequency of the sound emitted?

74. A 2.00-kg mass vibrates according to the equation $x = 0.650 \cos 7.40t$, 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 $x = 0.260$ m.

75. A simple pendulum oscillates with frequency f. What is its frequency if it accelerates at $0.50g$ (*a*) upward, and (*b*) downward?

76. A 220-kg wooden raft floats on a lake. When a 75-kg man stands on the raft, it sinks 4.0 cm deeper into the water. When he steps off, the raft vibrates for a while. (*a*) What is the frequency of vibration? (*b*) What is the total energy of vibration (ignoring damping)?

77. Two strings on a musical instrument are tuned to play at 392 Hz (G) and 440 Hz (A). (*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 is the ratio of their masses (m_G/m_A)? (*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 (L_G/L_A)? (*d*) If their masses and lengths are the same, what must be the ratio of the tensions in the two strings?

78. Consider a sine wave traveling down the stretched two-part cord of Fig. 11–33. Determine a formula (*a*) for the ratio of the speeds of the wave in the heavy section versus that in the lighter section, v_H/v_L, and (*b*) for the ratio of the wavelengths in the two sections. (The frequency is the same in both sections. Why?) (*c*) Is the wavelength greater in the heavier section of cord or the lighter?

79. A tuning fork vibrates at a frequency of 264 Hz, and the tip of each prong moves 1.8 mm to either side of center. Calculate (*a*) the maximum speed and (*b*) the maximum acceleration of the tip of a prong.

80. A diving board oscillates with simple harmonic motion of frequency 1.5 cycles per second. What is the maximum amplitude with which the end of the board can vibrate in order that a pebble placed there (Fig. 11–56) will not lose contact with the board during the oscillation?

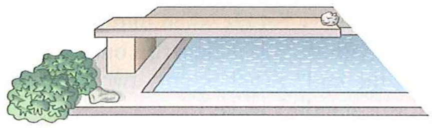

FIGURE 11–56 Problem 80.

81. 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. 11–57). Determine the wavelengths of the resonant vibrations of such a string with one end fixed and the other free.

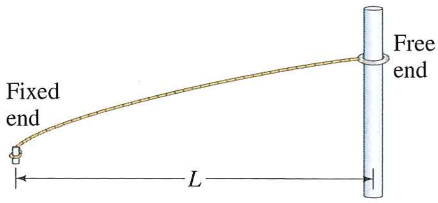

FIGURE 11–57 Problem 81.

82. A "seconds" pendulum has a period of exactly 2.000 s—each one-way swing takes 1.000 s. (*a*) What is the length of a seconds pendulum in Austin, Texas, where $g = 9.793\ \text{m/s}^2$? (*b*) If the pendulum is moved to Paris, where $g = 9.809\ \text{m/s}^2$, by how many millimeters must we lengthen the pendulum? (*c*) What would be the length of a seconds pendulum on the Moon, where $g = 1.62\ \text{m/s}^2$?

83. A mass hanging from a spring can oscillate in the vertical direction or can swing as a pendulum of small amplitude, but not both at the same time. Which one is longer, the period of the vertical oscillations or the period of the horizontal swings, and by what amount? [*Hint*: Let l_0 be the length of the unstretched spring, and L be its length with the mass attached at rest.]

84. A block with mass $M = 5.0\ \text{kg}$ 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?

85. A 10.0-m-long wire of mass 123 g is stretched under a tension of 255 N. A pulse is generated at one end, and 20.0 ms later a second pulse is generated at the opposite end. Where will the two pulses first meet?

86. 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 $m \ll M$.)

* 87. A crane has hoisted a 1200-kg car at the junkyard. The steel crane cable is 22 m long and has a diameter of 6.4 mm. A breeze starts the car bouncing at the end of the cable. What is the period of the bouncing? [*Hint*: Refer to Table 9–1.]

* 88. A block of jello rests on a plate as shown in Fig. 11–58 (which also gives the dimensions of the block). You push it sideways as shown, and then you let go. The jello springs back and begins to vibrate. In analogy to a mass vibrating on a spring, estimate the frequency of this vibration, given that the shear modulus (Section 9–5) of jello is $520\ \text{N/m}^2$ and its density is $1300\ \text{kg/m}^3$.

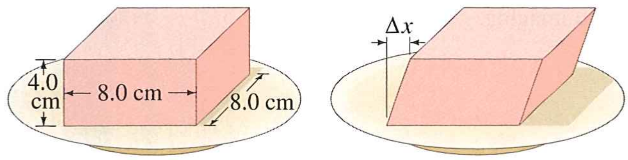

FIGURE 11–58 Problem 88.

Answers to Exercises

A: (*a*), (*c*), (*d*).

B: (*a*) Increases; (*b*) increases; (*c*) increases.

C: Empty.

D: (*a*) 25 cm; (*b*) 2.0 s.