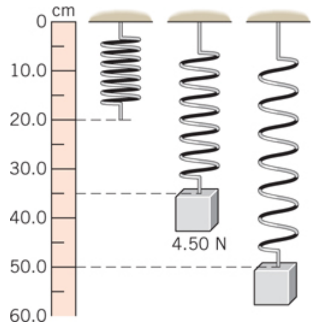
PROBLEMS

Section 10.1 The Ideal Spring and Simple Harmonic Motion

1. **ssm** A hand exerciser utilizes a coiled spring. A force of 89.0 N is required to compress the spring by 0.0191 m. Determine the force needed to compress the spring by 0.0508 m.

2. The drawing shows three identical springs hanging from the ceiling. Nothing is attached to the first spring, whereas a 4.50-N block hangs from the second spring. A block of unknown weight hangs from the third spring. From the drawing, determine **(a)** the spring constant (in N/m) and **(b)** the weight of the block hanging from the third spring.



Problem 2

3. In a room that is 2.44 m high, a spring (unstrained length = 0.30 m) hangs from the ceiling. A board whose length is 1.98 m is attached to the free end of the spring. The board hangs straight down, so that its 1.98-m length is perpendicular to the floor. The weight of the board (104 N) stretches the spring so that the lower end of the board just extends to, but does not touch, the floor. What is the spring constant of the spring?

4. A spring lies on a horizontal table, and the left end of the spring is attached to a wall. The other end is connected to a box. The box is pulled to the right, stretching the spring. Static friction exists between the box and the table, so when the spring is stretched only by a small amount and the box is released, the box does not move. The mass of the box is 0.80 kg, and the spring has a spring constant of 59 N/m. The coefficient of static friction between the box and the table on which it rests is $\mu_s = 0.74$. How far can the spring be stretched from its unstrained position without the box moving when it is released?

5. **ssm** A person who weighs 670 N steps onto a spring scale in the bathroom, and the spring compresses by 0.79 cm. **(a)** What is the spring constant? **(b)** What is the weight of another person who compresses the spring by 0.34 cm?

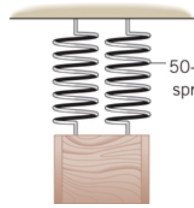
6. A spring (k = 830 N/m) is hanging from the ceiling of an elevator, and a 5.0-kg object is attached to the lower end. By how much does the spring stretch (relative to its unstrained length) when the elevator is accelerating upward at $a = 0.60\ \text{m/s}^2$?

7. A 0.70-kg block is hung from and stretches a spring that is attached to the ceiling. A second block is attached to the first one, and the amount that the spring stretches from its unstrained length triples. What is the mass of the second block?

***8.** A uniform 1.4-kg rod that is 0.75 m long is suspended at rest from the ceiling by two springs, one at each end of the rod. Both springs hang straight down from the ceiling. The springs have identical lengths when they are unstretched. Their spring constants are 59 N/m and 33 N/m. Find the angle that the rod makes with the horizontal.

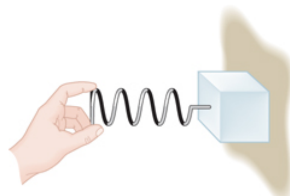
***9. ssm** In 0.750 s, a 7.00-kg block is pulled through a distance of 4.00 m on a frictionless horizontal surface, starting from rest. The block has a constant acceleration and is pulled by means of a horizontal spring that is attached to the block. The spring constant of the spring is 415 N/m. By how much does the spring stretch?

***10.** Review Conceptual Example 2 as an aid in solving this problem. An object is attached to the lower end of a 100-coil spring that is hanging from the ceiling. The spring stretches by 0.160 m. The spring is then cut into two identical springs of 50 coils each. As the drawing shows, each spring is attached between the ceiling and the object. By how much does each spring stretch?

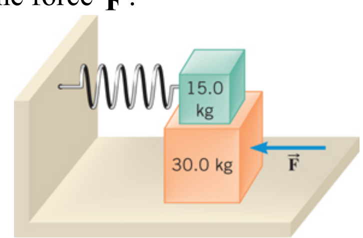


***11.** **ssm** A small ball is attached to one end of a spring that has an unstrained length of 0.200 m. The spring is held by the other end, and the ball is whirled around in a horizontal circle at a speed of 3.00 m/s. The spring remains nearly parallel to the ground during the motion and is observed to stretch by 0.010 m. By how much would the spring stretch if it were attached to the ceiling and the ball allowed to hang straight down, motionless?

***12. mmh** To measure the static friction coefficient between a 1.6-kg block and a vertical wall, the setup shown in the drawing is used. A spring (spring constant = 510 N/m) is attached to the block. Someone pushes on the end of the spring in a direction perpendicular to the wall until the block does not slip downward. The spring is compressed by 0.039 m. What is the coefficient of static friction?



****13.** A 30.0-kg block is resting on a flat horizontal table. On top of this block is resting a 15.0-kg block, to which a horizontal spring is attached, as the drawing illustrates. The spring constant of the spring is 325 N/m. The coefficient of kinetic friction between the lower block and the table is 0.600, and the coefficient of static friction between the two blocks is 0.900. A horizontal force $\vec{\mathbf{F}}$ is applied to the lower block as shown. This force is increasing in such a way as to keep the blocks moving at a *constant speed.* At the point where the upper block begins to slip on the lower block, determine **(a)** the amount by which the spring is compressed and **(b)** the magnitude of the force $\vec{\mathbf{F}}$.



****14.** A 15.0-kg block rests on a horizontal table and is attached to one end of a massless, horizontal spring. By pulling horizontally on the other end of the spring, someone causes the block to accelerate uniformly and reach a speed of 5.00 m/s in 0.500 s. In the process, the spring is stretched by 0.200 m. The block is then pulled at a *constant speed* of 5.00 m/s, during which time the spring is stretched by only 0.0500 m. Find **(a)** the spring constant of the spring and **(b)** the coefficient of kinetic friction between the block and the table.

Section 10.2 Simple Harmonic Motion and the Reference Circle

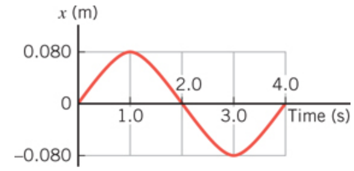
15. **ssm** When responding to sound, the human eardrum vibrates about its equilibrium position.

Suppose an eardrum is vibrating with an amplitude of 6.3×10^{-7} m and a maximum speed of 2.9×10^{-3} m/s. **(a)** What is the frequency (in Hz) of the eardrum's vibration? **(b)** What is the maximum acceleration of the eardrum?

16. The fan blades on a jet engine make one thousand revolutions in a time of 50.0 ms. Determine **(a)** the period (in seconds) and **(b)** the frequency (in Hz) of the rotational motion. **(c)** What is the angular frequency of the blades?

17. mmh A block of mass $m = 0.750$ kg is fastened to an unstrained horizontal spring whose spring constant is $k = 82.0$ N/m. The block is given a displacement of +0.120 m, where the + sign indicates that the displacement is along the $+x$ axis, and then released from rest. **(a)** What is the force (magnitude and direction) that the spring exerts on the block just before the block is released? **(b)** Find the angular frequency ω of the resulting oscillatory motion. **(c)** What is the maximum speed of the block? **(d)** Determine the magnitude of the maximum acceleration of the block.

18. mmh An 0.80-kg object is attached to one end of a spring, as in Figure 10.5, and the system is set into simple harmonic motion. The displacement x of the object as a function of time is shown in the drawing. With the aid of these data, determine **(a)** the amplitude A of the motion, **(b)** the angular frequency ω, **(c)** the spring constant k, **(d)** the speed of the object at $t = 1.0$ s, and **(e)** the magnitude of the object's acceleration at $t = 1.0$ s.



19. Refer to Conceptual Example 2 as an aid in solving this problem. A 100-coil spring has a spring constant of 420 N/m. It is cut into four shorter springs, each of which has 25 coils. One end of a 25-coil spring is attached to a wall. An object of mass 46 kg is attached to the other end of the spring, and the system is set into horizontal oscillation. What is the angular frequency of the motion?

***20.** Objects of equal mass are oscillating up and down in simple harmonic motion on two different vertical springs. The spring constant of spring 1 is 174 N/m. The motion of the object on spring 1 has twice the amplitude as the motion of the object on spring 2. The magnitude of the maximum velocity is the same in each case. Find the spring constant of spring 2.

***21. ssm mmh** A spring stretches by 0.018 m when a 2.8-kg object is suspended from its end. How much mass should be attached to this spring so that its frequency of vibration is $f = 3.0$ Hz?

***22.** An object attached to a horizontal spring is oscillating back and forth along a frictionless surface. The maximum speed of the object is 1.25 m/s, and its maximum acceleration is 6.89 m/s^2. How much time elapses between an instant when the object's speed is at a maximum and the next instant when its acceleration is at a maximum?

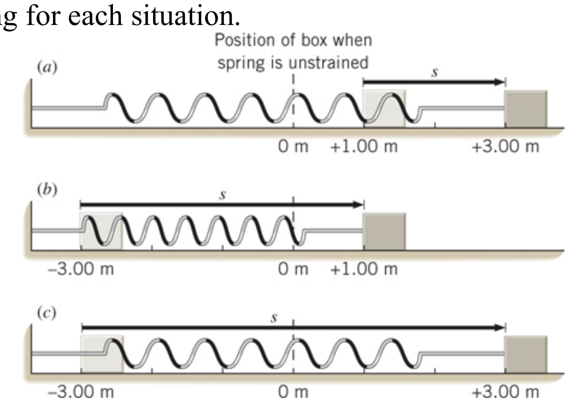
***23. mmh** A vertical spring (spring constant = 112 N/m) is mounted on the floor. A 0.400-kg block is placed on top of the spring and pushed down to start it oscillating in simple harmonic motion. The block is not attached to the spring. **(a)** Obtain the frequency (in Hz) of the motion.**(b)** Determine the amplitude at which the block will lose contact with the spring.

****24.** A tray is moved horizontally back and forth in simple harmonic motion at a frequency of $f = 2.00$ Hz. On this tray is an empty cup. Obtain the coefficient of static friction between the tray and the cup, given that the cup begins slipping when the amplitude of the motion is 5.00×10^{-2} m.

Section 10.3 Energy and Simple Harmonic Motion

25. A pen contains a spring with a spring constant of 250 N/m. When the tip of the pen is in its retracted position, the spring is compressed 5.0 mm from its unstrained length. In order to push the tip out and lock it into its writing position, the spring must be compressed an additional 6.0 mm. How much work is done by the spring force to ready the pen for writing? Be sure to include the proper algebraic sign with your answer.

26. The drawing shows three situations in which a block is attached to a spring. The position labeled "0 m" represents the unstrained position of the spring. The block is moved from an initial position x_0 to a final position x_f, the magnitude of the displacement being denoted by the symbol s. Suppose the spring has a spring constant of $k = 46.0$ N/m. Using the data provided in the drawing, determine the total work done by the restoring force of the spring for each situation.



27. A spring is hung from the ceiling. A 0.450-kg block is then attached to the free end of the spring. When released from rest, the block drops 0.150 m before momentarily coming to rest, after which it moves back upward. **(a)** What is the spring constant of the spring? **(b)** Find the angular frequency of the block's vibrations.

28. A 3.2-kg block is hanging stationary from the end of a vertical spring that is attached to the ceiling. The elastic potential energy of this spring-block system is 1.8 J. What is the elastic potential energy of the system when the 3.2-kg block is replaced by a 5.0-kg block?

29. ssm A vertical spring with a spring constant of 450 N/m is mounted on the floor. From directly above the spring, which is unstrained, a 0.30-kg block is dropped from rest. It collides with and sticks to the spring, which is compressed by 2.5 cm in bringing the block to a momentary halt. Assuming air resistance is negligible, from what height (in cm) above the compressed spring was the block dropped?

30. In preparation for shooting a ball in a pinball machine, a spring (k = 675 N/m) is compressed by 0.0650 m relative to its unstrained length. The ball (m = 0.0585 kg) is at rest against the spring at point A. When the spring is released, the ball slides (without rolling). It leaves the spring and arrives at point B, which is 0.300 m higher than point A. Ignore friction, and find the ball's speed at point B.

31. mmh A heavy-duty stapling gun uses a 0.140-kg metal rod that rams against the staple to eject it. The rod is attached to and pushed by a stiff spring called a "ram spring" (k = 32 000 N/m). The mass of this spring may be ignored. The ram spring is compressed by 3.0×10^{-2} m from its unstrained length and then released from rest. Assuming that the ram spring is oriented vertically and is still compressed by 0.8×10^{-2} m when the downward-moving ram hits the staple, find the speed of the ram at the instant of contact.

32. A rifle fires a 2.10×10^{-2}-kg pellet straight upward, because the pellet rests on a compressed spring that is released when the trigger is pulled. The spring has a negligible mass and is compressed by 9.10×10^{-2} m from its unstrained length. The pellet rises to a maximum height of 6.10 m above its position on the compressed spring. Ignoring air resistance, determine the spring constant.

33. ssm A 1.00×10^{-2}-kg block is resting on a horizontal frictionless surface and is attached to a horizontal spring whose spring constant is 124 N/m. The block is shoved parallel to the spring axis and is given an initial speed of 8.00 m/s, while the spring is initially unstrained. What is the amplitude of the resulting simple harmonic motion?

***34.** An 86.0-kg climber is scaling the vertical wall of a mountain. His safety rope is made of nylon that, when stretched, behaves like a spring with a spring constant of 1.20×10^3 N/m. He accidentally slips and falls freely for 0.750 m before the rope runs out of slack. How much is the rope stretched when it breaks his fall and momentarily brings him to rest?

***35.** A horizontal spring is lying on a frictionless surface. One end of the spring is attached to a wall, and the other end is connected to a movable object. The spring and object are compressed by 0.065 m, released from rest, and subsequently oscillate back and forth with an angular frequency of 11.3 rad/s. What is the speed of the object at the instant when the spring is *stretched* by 0.048 m relative to its unstrained length?

***36.** A spring is resting vertically on a table. A small box is dropped onto the top of the spring and compresses it. Suppose the spring has a spring constant of 450 N/m and the box has a mass of 1.5 kg. The speed of the box just before it makes contact with the spring is 0.49 m/s. **(a)** Determine the magnitude of the spring's displacement at an instant when the acceleration of the box is zero. **(b)** What is the magnitude of the spring's displacement when the spring is fully compressed?

***37. ssm mmh** A spring is compressed by 0.0620 m and is used to launch an object horizontally with a speed of 1.50 m/s. If the object were attached to the spring, at what angular frequency (in rad/s) would it oscillate?

***38.** A 0.60-kg metal sphere oscillates at the end of a vertical spring. As the spring stretches from 0.12 to 0.23 m (relative to its unstrained length), the speed of the sphere decreases from 5.70 to 4.80 m/s. What is the spring constant of the spring?

***39.** Review Conceptual Example 8 before starting this problem. A block is attached to a horizontal spring and oscillates back and forth on a frictionless horizontal surface at a frequency of 3.00 Hz. The amplitude of the motion is 5.08×10^{-2} m. At the point where the block has its maximum speed, it suddenly splits into two identical parts, only one part remaining attached to the spring. **(a)** What are the amplitude and the frequency of the simple harmonic motion that exists after the block splits? **(b)** Repeat part (a), assuming that the block splits when it is at one of its extreme positions.

***40.** A 1.1-kg object is suspended from a vertical spring whose spring constant is 120 N/m. **(a)** Find the amount by which the spring is stretched from its unstrained length. **(b)** The object is pulled straight down by an additional distance of 0.20 m and released from rest. Find the speed with which the object passes through its original position on the way up.

41. **ssm A 70.0-kg circus performer is fired from a cannon that is elevated at an angle of 40.0° above the horizontal. The cannon uses strong elastic bands to propel the performer, much in the same way that a slingshot fires a stone. Setting up for this stunt involves stretching the bands by 3.00 m from their unstrained length. At the point where the performer flies free of the bands, his height above the floor is the same as the height of the net into which he is shot. He takes 2.14 s to travel the horizontal distance of 26.8 m between this point and the net. Ignore friction and air resistance and determine the effective spring constant of the firing mechanism.

42. A 1.00×10^{-2}-kg bullet is fired horizontally into a 2.50-kg wooden block attached to one end of a massless horizontal spring ($k = 845$ N/m). The other end of the spring is fixed in place, and the spring is unstrained initially. The block rests on a horizontal, frictionless surface. The bullet strikes the block perpendicularly and quickly comes to a halt within it. As a result of this completely inelastic collision, the spring is compressed along its axis and causes the block/bullet to oscillate with an amplitude of 0.200 m. What is the speed of the bullet?

Section 10.4 The Pendulum

43. A simple pendulum is made from a 0.65-m-long string and a small ball attached to its free end. The ball is pulled to one side through a small angle and then released from rest. After the ball is released, how much time elapses before it attains its greatest speed?

44. **mmh** Astronauts on a distant planet set up a simple pendulum of length 1.2 m. The pendulum executes simple harmonic motion and makes 100 complete vibrations in 280 s. What is the magnitude of the acceleration due to gravity on this planet?

45. The length of a simple pendulum is 0.79 m and the mass of the particle (the "bob") at the end of the cable is 0.24 kg. The pendulum is pulled away from its equilibrium position by an angle of 8.508 and released from rest. Assume that friction can be neglected and that the resulting oscillatory motion is simple harmonic motion. **(a)** What is the angular frequency of the motion? **(b)** Using the position of the bob at its lowest point as the reference level, determine the total mechanical energy of the pendulum as it swings back and forth. **(c)** What is the bob's speed as it passes through the lowest point of the swing?

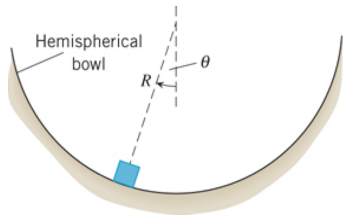
46. A spiral staircase winds up to the top of a tower in an old castle. To measure the height of the tower, a rope is attached to the top of the tower and hung down the center of the staircase. However, nothing is available with which to measure the length of the rope. Therefore, at the bottom of the rope a small object is attached so as to form a simple pendulum that just clears the floor. The period of the pendulum is measured to be 9.2 s. What is the height of the tower?

47. Two physical pendulums (not simple pendulums) are made from meter sticks that are suspended from the ceiling at one end. The sticks are uniform and are identical in all respects, except that one is made of wood (mass = 0.17 kg) and the other of metal (mass = 0.85 kg). They are set into oscillation and execute simple harmonic motion. Determine the period of **(a)** the wood pendulum and **(b)** the metal pendulum.

***48.** Multiple-Concept Example 11 explores the concepts that are important in this problem. Pendulum A is a physical pendulum made from a thin, rigid, and uniform rod whose length is d. One end of this rod is attached to the ceiling by a frictionless hinge, so the rod is free to swing back and forth. Pendulum B is a simple pendulum whose length is also d. Obtain the ratio T_A/T_B of their periods for small-angle oscillations.

***49.** Multiple-Concept Example 11 provides some pertinent background for this problem. A pendulum is constructed from a thin, rigid, and uniform rod with a small sphere attached to the end opposite the pivot. This arrangement is a good approximation to a simple pendulum (period = 0.66 s), because the mass of the sphere (lead) is much greater than the mass of the rod (aluminum). When the sphere is removed, the pendulum is no longer a simple pendulum, but is then a physical pendulum. What is the period of the physical pendulum?

****50.** A small object oscillates back and forth at the bottom of a frictionless hemispherical bowl, as the drawing illustrates. The radius of the bowl is R, and the angle θ is small enough that the object oscillates in simple harmonic motion. Derive an expression for the angular frequency ω of the motion. Express your answer in terms of R and g, the magnitude of the acceleration due to gravity.



Section 10.7 Elastic Deformation,
Section 10.8 Stress, Strain, and Hooke's Law

51. ssm A tow truck is pulling a car out of a ditch by means of a steel cable that is 9.1 m long and has a radius of 0.50 cm. When the car just begins to move, the tension in the cable is 890 N. How much has the cable stretched?

52. Two stretched cables both experience the same stress. The first cable has a radius of 3.5×10^{-3} m and is subject to a stretching force of 270 N. The radius of the second cable is 5.1×10^{-3} m. Determine the stretching force acting on the second cable.

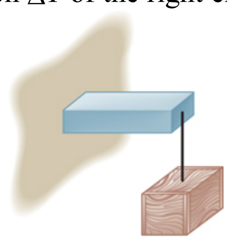
53. ssm The pressure increases by 1.0×10^{4} N/m^2 for every meter of depth beneath the surface of the ocean. At what depth does the volume of a Pyrex glass cube, 1.0×10^{-2} m on an edge at the ocean's surface, decrease by 1.0×10^{-10} m^3?

54. When subjected to a force of compression, the length of a bone decreases by 2.7×10^{-5} m. When this same bone is subjected to a tensile force of the same magnitude, by how much does it stretch?

55. A 59-kg water skier is being pulled by a nylon tow rope that is attached to a boat. The unstretched length of the rope is 12 m, and its cross-sectional area is 2.0×10^{-5} m^2. As the skier moves, a resistive force (due to the water) of magnitude 130 N acts on her; this force is directed opposite to her motion. What is the change in the length of the rope when the skier has an acceleration whose magnitude is 0.85 m/s^2?

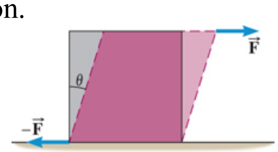
56. A solid steel cylinder is standing (on one of its ends) vertically on the floor. The length of the cylinder is 3.6 m and its radius is 65 cm. When an object is placed on top of the cylinder, the cylinder compresses by an amount of 5.7×10^{-7} m. What is the weight of the object?

57. The drawing shows a 160-kg crate hanging from the end of a steel bar. The length of the bar is 0.10 m, and its cross-sectional area is 3.2×10^{-4} m^2. Neglect the weight of the bar itself and determine **(a)** the shear stress on the bar and **(b)** the vertical deflection ΔY of the right end of the bar.



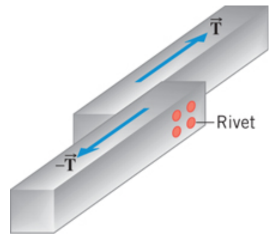
Problem 57

58. A copper cube, 0.30 m on a side, is subjected to two shearing forces, each of which has a magnitude $F = 6.0 \times 10^{6}$ N (see the drawing). Find the angle θ (in degrees), which is one measure of how the shape of the block has been altered by shear deformation.

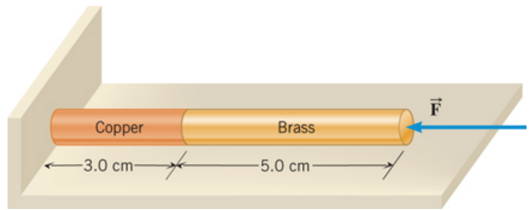


Problem 58

59. ssm Two metal beams are joined together by four rivets, as the drawing indicates. Each rivet has a radius of 5.0×10^{-3} m and is to be exposed to a shearing stress of no more than 5.0×10^{8} Pa. What is the maximum tension $\vec{T}$ that can be applied to each beam, assuming that each rivet carries one-fourth of the total load?



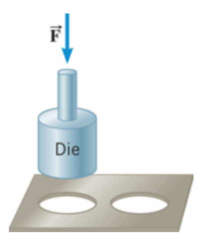
60. A copper cylinder and a brass cylinder are stacked end to end, as in the drawing. Each cylinder has a radius of 0.25 cm. A compressive force of $F = 6500$ N is applied to the right end of the brass cylinder. Find the amount by which the length of the stack decreases.



61. A piece of aluminum is surrounded by air at a pressure of 1.01×10^5 Pa. The aluminum is placed in a vacuum chamber where the pressure is reduced to zero. Determine the fractional change $\Delta V/V_0$ in the volume of the aluminum.

62. One end of a piano wire is wrapped around a cylindrical tuning peg and the other end is fixed in place. The tuning peg is turned so as to stretch the wire. The piano wire is made from steel ($Y = 2.0 \times 10^{11}$ N/m^2). It has a radius of 0.80 mm and an unstrained length of 0.76 m. The radius of the tuning peg is 1.8 mm. Initially, there is no tension in the wire, but when the tuning peg is turned, tension develops. Find the tension in the wire when the tuning peg is turned through two revolutions. Ignore the radius of the wire compared to the radius of the tuning peg.

*__63.__ A die is designed to punch holes with a radius of 1.00×10^{-2} m in a metal sheet that is 3.0×10^{-3} m thick, as the drawing illustrates. To punch through the sheet, the die must exert a shearing stress of 3.5×10^8 Pa. What force $\vec{F}$ must be applied to the die?



Problem 63

*__64.__ A piece of mohair taken from an Angora goat has a radius of 31×10^{-6} m. What is the least number of identical pieces of mohair needed to suspend a 75-kg person, so the strain experienced by each piece is less than 0.010? Assume that the tension is the same in all the pieces.

*__65.__ **ssm** Two rods are identical in all respects except one: one rod is made from aluminum and the other from tungsten. The rods are joined end to end, in order to make a single rod that is twice as long as either the aluminum or tungsten rod. What is the effective value of Young's modulus for this composite rod? That is, what value $Y_{\text{Composite}}$ of Young's modulus should be used in Equation 10.17 when applied to the composite rod? Note that the change $\Delta L_{\text{Composite}}$ in the length of the composite rod is the sum of the changes in length of the aluminum and tungsten rods.

*__66.__ A square plate is 1.0×10^{-2} m thick, measures 3.0×10^{-2} m on a side, and has a mass of 7.2×10^{-2} kg. The shear modulus of the material is 2.0×10^{10} N/m^2. One of the square faces rests on a flat horizontal surface, and the coefficient of static friction between the plate and the surface is 0.91. A force is applied to the top of the plate, as in Figure 10.29*a*. Determine **(a)** the maximum possible amount of shear stress, **(b)** the maximum possible amount of shear strain, and **(c)** the maximum possible amount of shear deformation ΔX (see Figure 10.29*b*) that can be created by the applied force just before the plate begins to move.

*__67.__ A gymnast does a one-arm handstand. The humerus, which is the upper arm bone (between the elbow and the shoulder joint), may be approximated as a 0.30-m-long cylinder with an outer radius of 1.00×10^{-2} m and a hollow inner core with a radius of 4.0×10^{-3} m. Excluding the arm, the mass of the gymnast is 63 kg. **(a)** What is the compressional strain of the humerus? **(b)** By how much is the humerus compressed?

***68.** Depending on how you fall, you can break a bone easily. The severity of the break depends on how much energy the bone absorbs in the accident, and to evaluate this let us treat the bone as an ideal spring. The maximum applied force of compression that one man's thighbone can endure without breaking is 7.0×10^4 N. The minimum effective cross-sectional area of the bone is 4.0×10^{-4} m^2, its length is 0.55 m, and Young's modulus is $Y = 9.4 \times 10^9$ N/m^2. The mass of the man is 65 kg. He falls straight down without rotating, strikes the ground stiff-legged on one foot, and comes to a halt without rotating. To see that it is easy to break a thighbone when falling in this fashion, find the maximum distance through which his center of gravity can fall without his breaking a bone.

***69. ssm** A 1.0×10^{-3}-kg spider is hanging vertically by a thread that has a Young's modulus of 4.5×10^9 N/m^2 and a radius of 13×10^{-6} m. Suppose that a 95-kg person is hanging vertically on an aluminum wire. What is the radius of the wire that would exhibit the same strain as the spider's thread, when the thread is stressed by the full weight of the spider?

***70.** The dimensions of a rectangular block of brass are 0.010 m, 0.020 m, and 0.040 m. The block is to be glued to a table and subjected to a horizontal force of 770 N, as in Figure 10.29. Note that there are three possibilities for the surface of the block that is in contact with the table. What is the maximum possible distance the top surface can move, relative to the bottom surface?

***71.** A 61-kg snow skier is being pulled up a 12° slope by a steel cable. The cable has a cross-sectional area of 7.8×10^{-5} m^2. The cable applies a force to the skier, and, in doing so, the cable stretches by 2.0×10^{-4} m. A frictional force of magnitude 68 N acts on the skis and is directed opposite to the skier's motion. If the skier's acceleration up the slope has a magnitude of 1.1 m/s^2, what is the original (unstretched) length of the cable?

****72.** A 6.8-kg bowling ball is attached to the end of a nylon cord with a cross-sectional area of 3.4×10^{-5} m^2. The other end of the cord is fixed to the ceiling. When the bowling ball is pulled to one side and released from rest, it swings downward in a circular arc. At the instant it reaches its lowest point, the bowling ball is 1.4 m lower than the point from which it was released, and the cord is stretched 2.7×10^{-3} m from its unstrained length. What is the unstrained length of the cord? (*Hint: When calculating any quantity other than the strain, ignore the increase in the length of the cord.)*

****73. ssm** A solid brass sphere is subjected to a pressure of 1.0×10^5 Pa due to the earth's atmosphere. On Venus the pressure due to the atmosphere is 9.0×10^6 Pa. By what fraction $\Delta r/r_0$ (including the algebraic sign) does the radius of the sphere change when it is exposed to the Venusian atmosphere? Assume that the change in radius is very small relative to the initial radius.

ADDITIONAL PROBLEMS

74. A loudspeaker diaphragm is producing a sound for 2.5 s by moving back and forth in simple harmonic motion. The angular frequency of the motion is 7.54×10^4 rad/s. How many times does the diaphragm move back and forth?

75. A person bounces up and down on a trampoline, while always staying in contact with it. The motion is simple harmonic motion, and it takes 1.90 s to complete one cycle. The height of each bounce above the equilibrium position is 45.0 cm. Determine **(a)** the amplitude and **(b)** the angular frequency of the motion. **(c)** What is the maximum speed attained by the person?

76. A simple pendulum is swinging back and forth through a small angle, its motion repeating every 1.25 s. How much longer should the pendulum be made in order to increase its period by 0.20 s?

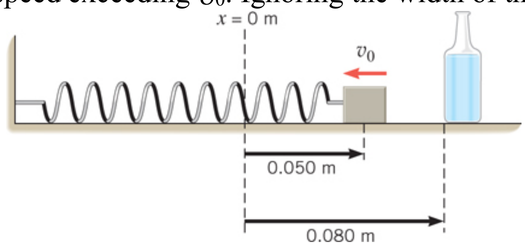
77. ssm Multiple-Concept Example 6 presents a model for solving this problem. As far as vertical oscillations are concerned, a certain automobile can be considered to be mounted on four identical springs, each having a spring constant of 1.30×10^5 N/m. Four identical passengers sit down inside the car, and it is set into a vertical oscillation that has a period of 0.370 s. If the mass of the empty car is 1560 kg, determine the mass of *each* passenger. Assume that the mass of the car and its passengers is distributed evenly over the springs.

78. The femur is a bone in the leg whose minimum cross-sectional area is about 4.0×10^{-4} m^2. A compressional force in excess of 6.8×10^4 N will fracture this bone. **(a)** Find the maximum stress that this bone can withstand. **(b)** What is the strain that exists under a maximum-stress condition?

79. An archer, about to shoot an arrow, is applying a force of +240 N to a drawn bowstring. The bow behaves like an ideal spring whose spring constant is 480 N/m. What is the displacement of the bowstring?

80. Between each pair of vertebrae in the spinal column is a cylindrical disc of cartilage. Typically, this disc has a radius of about 3.0×10^{-2} m and a thickness of about 7.0×10^{-3} m. The shear modulus of cartilage is 1.2×10^{7} N/m^2. Suppose that a shearing force of magnitude 11 N is applied parallel to the top surface of the disc while the bottom surface remains fixed in place. How far does the top surface move relative to the bottom surface?

***81.** A block rests on a frictionless horizontal surface and is attached to a spring. When set into simple harmonic motion, the block oscillates back and forth with an angular frequency of 7.0 rad/s. The drawing indicates the position of the block when the spring is unstrained. This position is labeled "$x = 0$ m." The drawing also shows a small bottle located 0.080 m to the right of this position. The block is pulled to the right, stretching the spring by 0.050 m, and is then thrown to the left. In order for the block to knock over the bottle, it must be thrown with a speed exceeding v_0. Ignoring the width of the block, find v_0.



***82.** A vertical ideal spring is mounted on the floor and has a spring constant of 170 N/m. A 0.64-kg block is placed on the spring in two different ways. **(a)** In one case, the block is placed on the spring and not released until it rests stationary on the spring in its equilibrium position. Determine the amount (magnitude only) by which the spring is compressed. **(b)** In a second situation, the block is released from rest immediately after being placed on the spring and falls downward until it comes to a momentary halt. Determine the amount (magnitude only) by which the spring is now compressed.

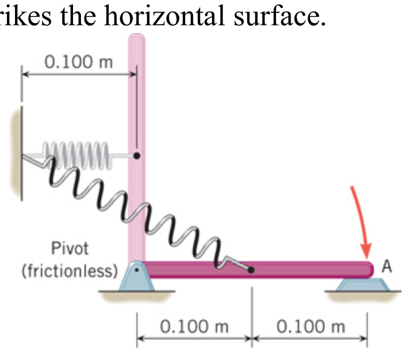
***83.** Multiple-Concept Example 6 reviews the principles that play roles in this problem. A bungee jumper, whose mass is 82 kg, jumps from a tall platform. After reaching his lowest point, he continues to oscillate up and down, reaching the low point two more times in 9.6 s. Ignoring air resistance and assuming that the bungee cord is an ideal spring, determine its spring constant.

***84. mmh** An 11.2-kg block and a 21.7-kg block are resting on a horizontal frictionless surface. Between the two is squeezed a spring (spring constant = 1330 N/m). The spring is compressed by 0.141 m from its unstrained length and is not attached to either block. With what speed does each block move away after the mechanism keeping the spring squeezed is released and the spring falls away?

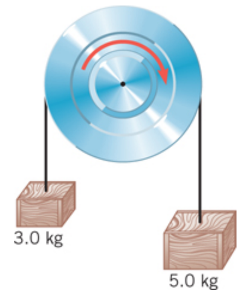
***85.** When an object of mass m_1 is hung on a vertical spring and set into vertical simple harmonic motion, it oscillates at a frequency of 12.0 Hz. When another object of mass m_2 is hung on the spring along with the first object, the frequency of the motion is 4.00 Hz. Find the ratio m_2/m_1 of the masses.

***86. ssm** An 8.0-kg stone at the end of a steel wire is being whirled in a circle at a constant tangential speed of 12 m/s. The stone is moving on the surface of a frictionless horizontal table. The wire is 4.0 m long and has a radius of 1.0×10^{-3} m. Find the strain in the wire.

****87.** A 0.200-m uniform bar has a mass of 0.750 kg and is released from rest in the vertical position, as the drawing indicates. The spring is initially unstrained and has a spring constant of $k = 25.0$ N/m. Find the tangential speed with which end A strikes the horizontal surface.



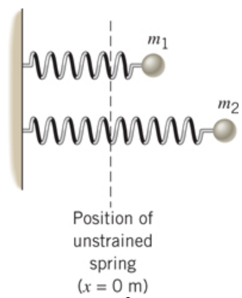
****88. ssm** The drawing shows two crates that are connected by a steel wire that passes over a pulley. The unstretched length of the wire is 1.5 m, and its cross-sectional area is 1.3×10^{-5} m^2. The pulley is frictionless and massless. When the crates are accelerating, determine the change in length of the wire. Ignore the mass of the wire.



Problem 88

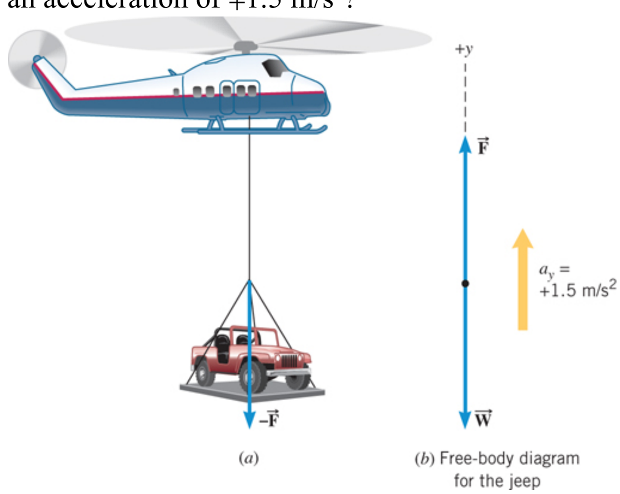
****89.** A cylindrically shaped piece of collagen (a substance found in the body in connective tissue) is being stretched by a force that increases from 0 to 3.0×10^{-2} N. The length and radius of the collagen are, respectively, 2.5 and 0.091 cm, and Young's modulus is 3.1×10^{6} N/m^2. **(a)** If the stretching obeys Hooke's law, what is the spring constant *k* for collagen? **(b)** How much work is done by the variable force that stretches the collagen? (See Section 6.9 for a discussion of the work done by a variable force.)

****90. ssm** The drawing shows a top view of a frictionless horizontal surface, where there are two springs with particles of mass m_1 and m_2 attached to them. Each spring has a spring constant of 120 N/m. The particles are pulled to the right and then released from the positions shown in the drawing. How much time passes before the particles are side by side for the first time at $x = 0$ m if **(a)** $m_1 = m_2 = 3.0$ kg and **(b)** $m_1 = 3.0$ kg and $m_2 = 27$ kg?



****91.** A copper rod (length = 2.0 m, radius = 3.0×10^{-3} m) hangs down from the ceiling. A 9.0-kg object is attached to the lower end of the rod. The rod acts as a "spring," and the object oscillates vertically with a small amplitude. Ignoring the rod's mass, find the frequency *f* of the simple harmonic motion.

***92.** A helicopter is using a steel cable to lift a 2100-kg jeep (see the figure). The unstretched length of the cable is 16 m, and its radius is 5.0×10^{-3} m. By what amount does the cable stretch when the jeep is hoisted straight upward with an acceleration of +1.5 m/s^2?

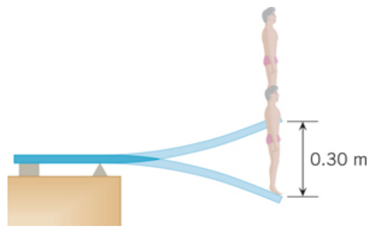


(*a*) The jeep applies a force $-\vec{F}$ to the lower end of the cable, thereby stretching it. (*b)* The free-body diagram for the jeep, showing the two forces acting on it.

CONCEPTS AND CALCULATIONS PROBLEMS

This chapter has examined an important kind of vibratory motion known as simple harmonic motion. Specifically, it has discussed how the motion's displacement, velocity, and acceleration vary with time, and explained what determines the frequency of the motion. In addition, we saw that the elastic force is conservative, so that the total mechanical energy is conserved if nonconservative forces, such as friction and air resistance, are absent. We conclude now with some problems that review important features of simple harmonic motion.

***93** **ssm** A 75-kg diver is standing at the end of a diving board while it is vibrating up and down in simple harmonic motion, as indicated in the figure. The diving board has an effective spring constant of $k = 4100$ N/m, and the vertical distance between the highest and lowest points in the motion is 0.30 m. *Concepts:* (i) How is the amplitude A related to the vertical distance between the highest and lowest points of the diver's motion? (ii) Starting from the top, where is the diver located one-quarter of a period later, and what can be said about his speed at this point? (iii) If the amplitude were to double, would the period also double? Explain. *Calculations:* **(a)** What is the amplitude of the motion? **(b)** Starting when the diver is at the highest point, what is his speed one-quarter of a period later? **(c)** If the vertical distance between his highest and lowest points were doubled to 0.60 m, what would be the time required for the diver to make one complete motional cycle?



***94.** A 68.0-kg bungee jumper is standing on a tall platform ($h_0 = 46.0$ m), as indicated in the figure. The bungee cord has a natural length of $L_0 = 9.00$ m and, when stretched, behaves like an ideal spring with a spring constant of $k = 66.0$ N/m. The jumper falls from rest, and it is assumed that the only forces acting on him are his weight and, for the latter part of the descent, the elastic force of the bungee cord. *Concepts:* (i) Can we use the conservation of mechanical energy to find his speed at any point along the descent? Explain your answer. (ii) What type of energy does he have when he is standing on the platform? (iii) What types of energy does he have at point A? (iv) What types of energy does he have at point B? *Calculations:* What is his speed when he is at the following heights above the water: **(a)** $h_A = 37.0$ m, and **(b)** $h_B = 15.0$ m?