3. If the stretch of a spring is doubled, the force it exerts is also doubled. By what factor does the spring’s potential energy increase?
4. When a mass is placed on top of a vertical spring, the spring compresses and the mass moves downward. Analyze this system in terms of its mechanical energy.
5. If a spring is stretched so far that it is permanently deformed, its force is no longer conservative. Why?
6. An object is thrown upward to a person on a roof. At what point is the object’s kinetic energy at maximum? At what point is the potential energy of the system at maximum? At what locations do these energies have their minimum values?
7. It is a law of nature that the total energy of the universe is conserved. What do politicians mean, then, when they urge “energy conservation”?
8. Discuss the various energy conversions that occur when a person performs a pole vault. Include as many conversions as you can, and consider times before, during, and after the actual vault itself.
9. Discuss the nature of the work done by the equipment shown in this photo. What types of forces are involved?

Conservative or nonconservative? (Conceptual Question 9)

10. A toy frog consists of a suction cup and a spring. When the suction cup is pressed against a smooth surface, the frog is held down. When the suction cup lets go, the frog leaps into the air. Discuss the behavior of the frog in terms of energy conversions.
11. If the force on an object is zero, does that mean the potential energy of the system is zero? If the potential energy of a system is zero, is the force zero?
12. When a ball is thrown upward, its mechanical energy, $E = mgy + \frac{1}{2}mv^2$, is constant with time if air resistance can be ignored. How does $E$ vary with time if air resistance cannot be ignored?
13. When a ball is thrown upward, it spends the same amount of time on the way up as on the way down—as long as air resistance can be ignored. If air resistance is taken into account, is the time on the way down the same as, greater than, or less than the time on the way up? Explain.

**PROBLEMS AND CONCEPTUAL EXERCISES**

*Note: Answers to odd-numbered Problems and Conceptual Exercises can be found in the back of the book. IP denotes an integrated problem, with both conceptual and numerical parts; BIO identifies problems of biological or medical interest; CE indicates a conceptual exercise. Predict/Explain problems ask for two responses: (a) your prediction of a physical outcome, and (b) the best explanation among three provided. On all problems, red bullets (•, ••, •••) are used to indicate the level of difficulty.*

**SECTION 8–1 CONSERVATIVE AND NONCONSERVATIVE FORCES**

1. • **CE** The work done by a conservative force is indicated in Figure 8–14 for a variety of different paths connecting the points A and B. What is the work done by this force (a) on path 1 and (b) on path 2?

   ![Figure 8–14 Problem 1](image)

2. • Calculate the work done by gravity as a 3.2-kg object is moved from point A to point B in Figure 8–15 along paths 1, 2, and 3.

   ![Figure 8–15 Problem 2](image)

3. • Calculate the work done by friction as a 3.7-kg box is slid along a floor from point A to point B in Figure 8–16 along paths 1, 2, and 3. Assume that the coefficient of kinetic friction between the box and the floor is 0.26.

   ![Figure 8–16 Problem 3](image)
4. • IPA A 4.1-kg block is attached to a spring with a force constant of 550 N/m, as shown in Figure 8-17. (a) Find the work done by the spring on the block as the block moves from A to B along paths 1 and 2. (b) How do your results depend on the mass of the block? Specifically, if you increase the mass, does the work done by the spring increase, decrease, or stay the same? (Assume the system is frictionless.)

![Figure 8-17](image)

5. • IP (a) Calculate the work done by gravity as a 5.2-kg object is moved from A to B in Figure 8-18 along paths 1 and 2. (b) How do your results depend on the mass of the block? Specifically, if you increase the mass, does the work done by gravity increase, decrease, or stay the same?

![Figure 8-18](image)

6. • In the system shown in Figure 8-17, suppose the block has a mass of 2.7 kg, the spring has a force constant of 480 N/m, and the coefficient of kinetic friction between the block and the floor is 0.16. (a) Find the work done on the block by the spring and by friction as the block is moved from point A to point B along path 2. (b) Find the work done on the block by the spring and by friction if the block is moved directly from point A to point B.

![Figure 8-19](image)

SECTION 8-2 POTENTIAL ENERGY AND THE WORK DONE BY CONSERVATIVE FORCES

7. • CE Predict/Explain Ball 1 is thrown to the ground with an initial downward speed; ball 2 is dropped to the ground from rest. Assuming the balls have the same mass and are released from the same height, is the change in gravitational potential energy of ball 1 greater than, less than, or equal to the change in gravitational potential energy of ball 2? (b) Choose the best explanation from among the following:
I. Ball 1 has the greater total energy, and therefore more energy can go into gravitational potential energy.
II. The gravitational potential energy depends only on the mass of the ball and the drop height.
III. All of the initial energy of ball 2 is gravitational potential energy.

8. • CE A mass is attached to the bottom of a vertical spring. This causes the spring to stretch and the mass to move downward. (a) Does the potential energy of the spring increase, decrease, or stay the same during this process? Explain. (b) Does the gravitational potential energy of the Earth–mass system increase, decrease, or stay the same during this process? Explain.

9. • As an Acapulco cliff diver drops to the water from a height of 46 m, his gravitational potential energy decreases by 25,000 J. What is the diver's weight in newtons?

10. • Find the gravitational potential energy of an 88-kg person standing atop Mt. Everest at an altitude of 8845 m. Use sea level as the location for y = 0.

11. • Jeopardy! Contestants on the game show Jeopardy! depress spring-loaded buttons to "buzz in" and provide the question corresponding to the revealed answer. The force constant on these buttons is about 130 N/m. Estimate the amount of energy it takes—at a minimum—to buzz in.

12. • BIO The Wing of the Hawkmoth Experiments performed on the wing of a hawkmoth (Manduca sexta) show that it deflects by a distance of x = 4.8 mm when a force of magnitude \( F = 3.0 \text{ mN} \) is applied at the tip, as indicated in Figure 8-19. Treating the wing as an ideal spring, find (a) the force constant of the wing and (b) the energy stored in the wing when it is deflected. (c) What force must be applied to the tip of the wing to store twice the energy found in part (b)?

![Hummingbird hawkmoth (Manduca sexta).](image)

13. • IPA A vertical spring stores 0.962 J in spring potential energy when a 3.5-kg mass is suspended from it. (a) By what multiplicative factor does the spring potential energy change if the mass attached to the spring is doubled? (b) Verify your answer to part (a) by calculating the spring potential energy when a 7.0-kg mass is attached to the spring.

14. • Pushing on the pump of a soap dispenser compresses a small spring. When the spring is compressed 0.50 cm, its potential energy is 0.0025 J. (a) What is the force constant of the spring? (b) What compression is required for the spring potential energy to equal 0.0084 J?

15. • A force of 4.1 N is required to stretch a certain spring by 1.4 cm. (a) How far must this spring be stretched for its potential energy to be 0.020 J? (b) How much stretch is required for the spring potential energy to be 0.080 J?

16. • IP The work required to stretch a certain spring from an elongation of 4.00 cm to an elongation of 5.00 cm is 30.5 J. (a) Is the work required to increase the elongation of the spring from 5.00 cm to 6.00 cm greater than, less than, or equal to 30.5 J? Explain. (b) Verify your answer to part (a) by calculating the required work.
17. A 0.33-kg pendulum bob is attached to a string 1.2 m long. What is the change in the gravitational potential energy of the system as the bob swings from point A to point B in Figure 8–20?

![Figure 8–20](image)

**SECTION 8–3 CONSERVATION OF MECHANICAL ENERGY**

18. **CE Predict/Explain** You throw a ball upward and let it fall to the ground. Your friend drops an identical ball straight down to the ground from the same height. Is the change in the kinetic energy of your ball greater than, less than, or equal to the change in kinetic energy of your friend’s ball? (b) Choose the best explanation from among the following:
   I. Your friend’s ball converts all its initial energy into kinetic energy.
   II. Your ball is in the air longer, which results in a greater change in kinetic energy.
   III. The change in gravitational potential energy is the same for each ball, which means the change in kinetic energy must be the same also.

19. **CE** Suppose the situation described in Conceptual Checkpoint 8–2 is repeated on the fictional planet Epsilon, where the acceleration due to gravity is less than it is on the Earth.
   (a) Would the height of a hill on Epsilon that causes a reduction in speed from 4 m/s to 0 be greater than, less than, or equal to the height of the corresponding hill on Earth? Explain. (b) Consider the hill on Epsilon discussed in part (a). If the initial speed at the bottom of the hill is 5 m/s, will the final speed at the top of the hill be greater than, less than, or equal to 3 m/s? Explain.

20. **CE Predict/Explain** When a ball of mass m is dropped from rest from a height h, its kinetic energy just before landing is K. Now, suppose a second ball of mass 4m is dropped from rest from a height h/4.
   (a) Just before ball 2 lands, is its kinetic energy 4K, 2K, K, K/2, or K/4? (b) Choose the best explanation from among the following:
   I. The two balls have the same initial energy.
   II. The more massive ball will have the greater kinetic energy.
   III. The reduced drop height results in a reduced kinetic energy.

21. **CE Predict/Explain** When a ball of mass m is dropped from rest from a height h, its speed just before landing is v. Now, suppose a second ball of mass 4m is dropped from rest from a height h/4.
   (a) Just before ball 2 lands, is its speed 4v, 2v, v, v/2, or v/4? (b) Choose the best explanation from among the following:
   I. The factors of 4 cancel; therefore, the landing speed is the same.
   II. The two balls land with the same kinetic energy; therefore, the ball of mass 4m has the speed v/2.
   III. Reducing the height by a factor of 4 reduces the speed by a factor of 4.

22. **CE** For an object moving along the x axis, the potential energy of the frictionless system is shown in Figure 8–21. Suppose the object is released from rest at the point A. Rank the other points in the figure in increasing order of the object’s speed. Indicate ties where appropriate.

![Figure 8–21](image)

23. **CE** Referring to Problem 22, suppose the object is released from rest at a point halfway between the points F and G. Rank the other points in the figure in increasing order of the object’s speed if the object can reach that point. Indicate ties where appropriate.

24. At an amusement park, a swimmer uses a water slide to enter the main pool. If the swimmer starts at rest, slides without friction, and descends through a vertical height of 2.31 m, what is her speed at the bottom of the slide?

25. In the previous problem, find the swimmer’s speed at the bottom of the slide if she starts with an initial speed of 0.840 m/s.

26. **IP** A player passes a 0.600-kg basketball downcourt for a fast break. The ball leaves the player’s hands with a speed of 8.30 m/s and slows down to 7.10 m/s at its highest point. (a) Ignoring air resistance, how high above the release point is the ball when it is at its maximum height? (b) How would doubling the ball’s mass affect the result in part (a)? Explain.

27. **CE** Three balls are thrown upward with the same initial speed $v_0$, but at different angles relative to the horizontal, as shown in Figure 8–22. Ignoring air resistance, indicate which of the following statements is correct: At the dashed level, (A) ball 3 has the lowest speed; (B) ball 1 has the lowest speed; (C) all three balls have the same speed; (D) the speed of the balls depends on their mass.

![Figure 8–22](image)

28. **IP** In a tennis match, a player wins a point by hitting the ball sharply to the ground on the opponent’s side of the net. (a) If the ball bounces upward from the ground with a speed of 16 m/s, and is caught by a fan in the stands with a speed of 12 m/s, how high above the court is the fan? Ignore air resistance. (b) Explain why it is not necessary to know the mass of the tennis ball.

29. A 0.21-kg apple falls from a tree to the ground, 4.0 m below. Ignoring air resistance, determine the apple’s kinetic energy, K, the gravitational potential energy of the system, U, and the total mechanical energy of the system, E, when the apple’s height above the ground is (a) 4.0 m, (b) 3.0 m, (c) 2.0 m, (d) 1.0 m, and (e) 0 m. Take ground level to be y = 0.

30. **IP** A 2.9-kg block slides with a speed of 1.6 m/s on a frictionless horizontal surface until it encounters a spring. (a) If the block compresses the spring 4.8 cm before coming to rest, what is the force constant of the spring? (b) What initial speed should the block have to compress the spring by 1.2 cm?
31. A 0.26-kg rock is thrown vertically upward from the top of a cliff that is 32 m high. When it hits the ground at the base of the cliff, the rock has a speed of 29 m/s. Assuming that air resistance can be ignored, find (a) the initial speed of the rock and (b) the greatest height of the rock as measured from the base of the cliff.

32. A 1.40-kg block slides with a speed of 0.950 m/s on a frictionless horizontal surface until it encounters a spring with a force constant of 734 N/m. The block comes to rest after compressing the spring 4.15 cm. Find the spring potential energy, \( \mathcal{U} \), the kinetic energy of the block, \( K \), and the total mechanical energy of the system, \( \mathcal{E} \), for compressions of (a) 0 cm, (b) 1.00 cm, (c) 2.00 cm, (d) 3.00 cm, and (e) 4.00 cm.

33. A 5.76-kg rock is dropped and allowed to fall freely. Find the initial kinetic energy, the final kinetic energy, and the change in kinetic energy for (a) the first 2.00 m of fall and (b) the second 2.00 m of fall.

34. Suppose the pendulum bob in Figure 8–20 has a mass of 0.33 kg and is moving to the right at point B with a speed of 2.4 m/s. Air resistance is negligible. (a) What is the change in the system’s gravitational potential energy when the bob reaches point A? (b) What is the speed of the bob at point A? (c) If the mass of the bob is increased, does your answer to part (a) increase, decrease, or stay the same? Explain. (d) If the mass of the bob is increased, does your answer to part (b) increase, decrease, or stay the same? Explain.

35. In the previous problem, (a) what is the bob’s kinetic energy at point B? (b) At some point the bob will come to rest momentarily. Without doing an additional calculation, determine the change in energy of the system due to the bob coming to rest. (c) Find the maximum angle the string makes with the vertical as the bob swings back and forth. Ignore air resistance.

36. The two masses in the Atwood’s machine shown in Figure 8–23 are initially at rest at the same height. After they are released, the large mass, \( m_2 \), falls through a height \( h \) and hits the floor, and the small mass, \( m_1 \), rises through a height \( h \). (a) Find the speed of the masses just before lands give, your answer in terms of \( m_1, m_2, g \), and \( h \). Assume the ropes and pulley have negligible mass and that friction can be ignored. (b) Evaluate your answer to part (a) for the case \( h = 1.2 \) m, \( m_1 = 3.7 \) kg, and \( m_2 = 4.1 \) kg.

37. In the previous problem, suppose the masses have an initial speed of 0.20 m/s, and that \( m_2 \) is moving upward. How high does \( m_2 \) rise above its initial position before momentarily coming to rest, given that \( m_1 = 3.7 \) kg and \( m_2 = 4.1 \) kg?

![Figure 8–23 Problems 36, 37, 82, and 99](image)

38. You coast up a hill on your bicycle with decreasing speed. Your friend pedals up the hill with constant speed. (a) Ignoring friction, does the mechanical energy of the you–bike–Earth system increase, decrease, or stay the same? Explain. (b) Does the mechanical energy of the friend–bike–Earth system increase, decrease, or stay the same? Explain.

39. Predict/Explain On reentry, the space shuttle’s protective heat tiles become extremely hot. (a) Is the mechanical energy of the shuttle–Earth system when the shuttle lands greater than, less than, or the same as when it is in orbit? (b) Choose the best explanation from among the following:
   I. Dropping out if orbit increases the mechanical energy of the shuttle.
   II. Gravity is a conservative force.
   III. A portion of the mechanical energy has been converted to heat energy.

40. Catching a wave, a 77-kg surfer starts with a speed of 1.3 m/s, drops through a height of 1.65 m, and ends with a speed of 8.2 m/s. How much nonconservative work was done on the surfer?

41. At a playground, a 19-kg child plays on a slide that drops through a height of 2.3 m. The child starts at rest at the top of the slide. On the way down, the slide does a nonconservative work of –361 J on the child. What is the child’s speed at the bottom of the slide?

42. Starting at rest at the edge of a swimming pool, a 72.0-kg athlete swims along the surface of the water and reaches a speed of 1.20 m/s by doing the work \( W_{\text{rel}} = +161 \) J. Find the nonconservative work, \( W_{\text{rel}} \), done by the water on the athlete.

43. A 17,000-kg airplane lands with a speed of 82 m/s on a stationary aircraft carrier deck that is 115 m long. Find the work done by nonconservative forces in stopping the plane.

44. The driver of a 1300-kg car moving at 17 m/s brakes quickly to 11 m/s when he spots a local garage sale. (a) Find the change in the car’s kinetic energy. (b) Explain where the “missing” kinetic energy has gone.

45. You ride your bicycle down a hill, maintaining a constant speed the entire time. (a) As you ride, does the gravitational potential energy of the you–bike–Earth system increase, decrease, or stay the same? Explain. (b) Does the kinetic energy of you and your bike increase, decrease, or stay the same? Explain. (c) Does the mechanical energy of the you–bike–Earth system increase, decrease, or stay the same? Explain.

46. Suppose the system in Example 8–10 starts with \( m_2 \) moving downward with a speed of 1.3 m/s. What speed do the masses have just before \( m_2 \) lands?

47. A 42.0-kg seal at an amusement park slides from rest down a ramp into the pool below. The top of the ramp is 1.75 m higher than the surface of the water, and the ramp is inclined at an angle of 35.0° above the horizontal. If the seal reaches the water with a speed of 4.40 m/s, what are (a) the work done by kinetic friction and (b) the coefficient of kinetic friction between the seal and the ramp?

48. A 1.9-kg rock is released from rest at the surface of a pond 1.8 m deep. As the rock falls, a constant upward force of 4.6 N is exerted on it by water resistance. Calculate the nonconservative work, \( W_{\text{rel}} \), done by water resistance on the rock, the gravitational potential energy of the system, \( U \), the kinetic energy of the rock, \( K \), and the total mechanical energy of the system, \( \mathcal{E} \), when the depth of the rock below the water’s surface is (a) 0 m, (b) 0.50 m, and (c) 1.0 m. Let \( y = 0 \) be at the bottom of the pond.
49. A 1250-kg car drives up a hill that is 16.2 m high. During the drive, two nonconservative forces do work on the car: (i) the force of friction, and (ii) the force generated by the car’s engine. The work done by friction is \(-3.11 \times 10^5\) J, and the work done by the engine is \(+6.44 \times 10^5\) J. Find the change in the car’s kinetic energy from the bottom of the hill to the top of the hill.

50. An 81.0-kg in-line skater does \(+3420\) J of nonconservative work by pushing against the ground with his skates. In addition, friction does \(-715\) J of nonconservative work on the skater. The skater’s initial and final speeds are 2.50 m/s and 1.22 m/s, respectively. (a) Has the skater gone uphill, downhill, or remained at the same level? Explain. (b) Calculate the change in height of the skater.

51. In Example 8-10, suppose the two masses start from rest and are moving with a speed of 2.05 m/s just before \(m_2\) hits the floor. (a) If the coefficient of kinetic friction is \(\mu_k = 0.350\), what is the distance of travel, \(d\), for the masses? (b) How much conservative work was done on this system? (c) How much nonconservative work was done on this system? (d) Verify the three work relations given in Equations 8-10.

52. A 15,800-kg truck is moving at 12.0 m/s when it starts down a 6.00° incline in the Canadian Rockies. At the start of the descent the driver notices that the altitude is 1630 m. When she reaches an altitude of 1440 m, her speed is 29.0 m/s. Find the change in (a) the gravitational potential energy of the system and (b) the truck’s kinetic energy. (c) Is the total mechanical energy of the system conserved? Explain.

53. A 1.80-kg block slides on a rough horizontal surface. The block hits a spring with a speed of 2.00 m/s and compresses it a distance of 11.0 cm before coming to rest. If the coefficient of kinetic friction between the block and the surface is \(\mu_k = 0.560\), what is the force constant of the spring?

SECTION 8-5 POTENTIAL ENERGY CURVES AND EQUIPOTENTIALS

54. Figure 8-24 shows a potential energy curve as a function of \(x\). In qualitative terms, describe the subsequent motion of an object that starts at rest at point A.

55. An object moves along the \(x\) axis, subject to the potential energy shown in Figure 8-24. The object has a mass of 1.1 kg and starts at rest at point A. (a) What is the object’s speed at point B? (b) At point C? (c) At point D? (d) What are the turning points for this object?

56. A 1.34-kg object moves along the \(x\) axis, subject to the potential energy shown in Figure 8-24. If the object’s speed at point C is 1.25 m/s, what are the approximate locations of its turning points?

57. A 23-kg child swings back and forth on a swing suspended by 2.5-m-long ropes. Plot the gravitational potential energy of this system as a function of the angle the ropes make with the vertical, assuming the potential energy is zero when the ropes are vertical. Consider angles up to 90° on either side of the vertical.

58. Find the turning-point angles in the previous problem if the child has a speed of 0.89 m/s when the ropes are vertical. Indicate the turning points on a plot of the system’s potential energy.

59. The potential energy of a particle moving along the \(x\) axis is shown in Figure 8-24. When the particle is at \(x = 1.0\) m it has 3.6 J of kinetic energy. Give approximate answers to the following questions. (a) What is the total mechanical energy of the system? (b) What is the smallest value of \(x\) the particle can reach? (c) What is the largest value of \(x\) the particle can reach?

60. A block of mass \(m = 0.95\) kg is connected to a spring of force constant \(k = 775\) N/m on a smooth, horizontal surface. (a) Plot the potential energy of the spring from \(x = -5.00\) cm to \(x = 5.00\) cm. (b) Determine the turning points of the block if its speed at \(x = 0\) is 1.3 m/s.

61. A ball of mass \(m = 0.75\) kg is thrown straight upward with an initial speed of 8.9 m/s. (a) Plot the gravitational potential energy of the block from its launch height, \(y = 0\), to the height \(y = 5.0\) m. Let \(U = 0\) correspond to \(y = 0\). (b) Determine the turning point (maximum height) of this mass.

62. Two blocks, each of mass \(m\), are connected on a frictionless horizontal table by a spring of force constant \(k\) and equilibrium length \(L\). Find the maximum and minimum separation between the two blocks in terms of their maximum speed, \(v_{\text{max}}\), relative to the table. (The two blocks always move in opposite directions as they oscillate back and forth about a fixed position.)

GENERAL PROBLEMS

63. A friend both solve a problem involving a skier going down a slope. When comparing solutions, you notice that your choice for the \(y = 0\) level is different than the \(y = 0\) level chosen by your friend. Will your answers agree or disagree on the following quantities: (a) the skier’s potential energy; (b) the skier’s change in potential energy; (c) the skier’s kinetic energy?

64. A particle moves under the influence of a conservative force. At point A the particle has a kinetic energy of 12 J; at point B the particle is momentarily at rest, and the potential energy of the system is 25 J; at point C the potential energy of the system is 5 J. (a) What is the potential energy of the system when the particle is at point A? (b) What is the kinetic energy of the particle at point C?

65. A leaf falls to the ground with constant speed. Is \(U + K\) for this system greater than, less than, or the same as \(U + K\) for this system? Explain.

66. Consider the two-block system shown in Example 8-10. (a) As block 2 descends through the distance \(d\), does its mechanical energy increase, decrease, or stay the same? Explain. (b) Is the nonconservative work done on block 2 by the tension in the rope positive, negative, or zero? Explain.

67. Taking a leap of faith, a bungee jumper steps off a platform and falls until the cord brings her to rest. Suppose you analyze this system by choosing \(y = 0\) at the platform level, and your friend chooses \(y = 0\) at ground level. (a) Is the jumper’s initial potential energy in your calculation greater than, less than, or equal to the same quantity in your friend’s calculation? Explain. (b) Is the change in the jumper’s potential energy in your calculation greater than, less than, or equal to the same quantity in your friend’s calculation? Explain.

68. A sled slides without friction down a small, ice-covered hill. If the sled starts from rest at the bottom of the hill, its speed at the bottom is 7.50 m/s. (a) On a second run, the sled starts with a speed of 1.50 m/s at the top. When it reaches the bottom of the hill, its speed is 9.00 m/s, more than 9.00 m/s, or less than 9.00 m/s? Explain. (b) Find the speed of the sled at the bottom of the hill after the second run.
69. •• In the previous problem, what is the height of the hill?

70. •• A 68-kg skier encounters a dip in the snow’s surface that has a circular cross section with a radius of curvature of 12 m. If the skier’s speed at point A in Figure 8–25 is 8.0 m/s, what is the normal force exerted by the snow on the skier at point B? Ignore frictional forces.

![Figure 8–25](image)

71. •• Running Shoes The soles of a popular make of running shoe have a force constant of \(2.0 \times 10^5\) N/m. Treat the soles as ideal springs for the following questions. (a) If a 62-kg person stands in a pair of these shoes, with her weight distributed equally on both feet, how much does she compress the soles? (b) How much energy is stored in the soles of her shoes when she’s standing?

72. •• Nasal Strips The force required to flex a nasal strip and apply it to the nose is 0.25 N; the energy stored in the strip when flexed is 0.0022 J. Assume the strip to be an ideal spring for the following calculations. Find (a) the distance through which the strip is flexed and (b) the force constant of the strip.

73. •• IP A pendulum bob with a mass of 0.13 kg is attached to a string with a length of 0.95 m. We choose the potential energy to be zero when the string makes an angle of 90° with the vertical. (a) Find the potential energy of this system when the string makes an angle of 45° with the vertical. (b) Is the magnitude of the change in potential energy from an angle of 90° to 45° greater than, less than, or the same as the magnitude of the change from 45° to 0°? Explain. (c) Calculate the potential energy of the system when the string is vertical.

74. •• Suppose the pendulum bob in Figure 8–20 has a mass of 0.25 kg. (a) How much work does gravity do on the bob as it moves from point A to point B? (b) From point B to point A? (c) How much work does the string do on the bob as it moves from point A to point B? (d) From point B to point A?

75. •• An 1865-kg airplane starts at rest on an airport runway at sea level. (a) What is the change in mechanical energy of the airplane if it climbs to a cruising altitude of 2420 m and maintains a constant speed of 96.5 m/s? (b) What cruising speed would the plane need at this altitude if its increase in kinetic energy is to be equal to its increase in potential energy?

76. •• IP At the local playground a child on a swing has a speed of 2.02 m/s when the swing is at its lowest point. (a) To what maximum vertical height does the child rise, assuming he sits still and “coasts”? Ignore air resistance. (b) How do your results change if the initial speed of the child is halved?

77. •• The water slide shown in Figure 8–26 ends at a height of 1.50 m above the pool. If the person starts at rest at point A and lands in the water at point B, what is the height of the water slide? (Assume the water slide is frictionless.)

78. •• If the height of the water slide in Figure 8–26 is \(h = 3.2\) m, and the person’s initial speed at point A is 0.54 m/s, what is the new horizontal distance between the base of the slide and the splashdown point of the person?

79. •• IP A person is to be released from rest on a swing pulled away from the vertical by an angle of 20.0°. The two frayed ropes of the swing are 2.75 m long, and will break if the tension in either of them exceeds 355 N. (a) What is the maximum weight the person can have and not break the ropes? (b) If the person is released at an angle greater than 20.0°, does the maximum weight increase, decrease, or stay the same? Explain.

80. •• IP A car is coasting without friction toward a hill of height \(h\) and radius of curvature \(r\). (a) What initial speed, \(v_0\), will result in the car’s wheels just losing contact with the roadway as the car crests the hill? (b) What happens if the initial speed of the car is greater than the value found in part (a)?

81. •• A skateboarder starts at point A in Figure 8–27 and rises to a height of 2.64 m above the top of the ramp at point B. What was the skateboarder’s initial speed at point A?

82. •• In the Atwood’s machine of Problem 36, the mass \(m_2\) remains at rest once it hits the floor, but the mass \(m_1\) continues moving upward. How much higher does \(m_1\) go after \(m_2\) has landed? Give your answer for the case \(h = 1.2\) m, \(m_1 = 3.7\) kg, and \(m_2 = 4.1\) kg.

83. •• An 8.70-kg block slides with an initial speed of 1.56 m/s up a ramp inclined at an angle of 28.4° with the horizontal. The coefficient of kinetic friction between the block and the ramp is 0.62. Use energy conservation to find the distance the block slides before coming to rest.

84. •• Repeat the previous problem for the case of an 8.70-kg block sliding down the ramp, with an initial speed of 1.56 m/s.

85. •• Jeff of the Jungle swings on a 7.6-m vine that initially makes an angle of 37° with the vertical. If Jeff starts at rest and has a mass of 78 kg, what is the tension in the vine at the lowest point of the swing?
86. ** A 1.9-kg block slides down a frictionless ramp, as shown in Figure 8–28. The top of the ramp is 1.5 m above the ground; the bottom of the ramp is 0.25 m above the ground. The block leaves the ramp moving horizontally, and lands a horizontal distance \( d \) away. Find the distance \( d \).

![Figure 8–28 Problems 86 and 87](image)

93. ** An ice cube is placed on top of an overturned spherical bowl of radius \( r \), as indicated in Figure 8–30. If the ice cube slides downward from rest at the top of the bowl, at what angle \( \theta \) does it separate from the bowl? In other words, at what angle does the normal force between the ice cube and the bowl go to zero?

![Figure 8–30 Problem 93](image)

94. ** IP The two blocks shown in Figure 8–31 are moving with an initial speed \( v \). (a) If the system is frictionless, find the distance \( d \) the blocks travel before coming to rest. (Let \( U = 0 \) correspond to the initial position of block 2.) (b) Is the work done on block 2 by the rope positive, negative, or zero? Explain. (c) Calculate the work done on block 2 by the rope.

![Figure 8–31 Problems 94 and 95](image)

95. ** IP Consider the system shown in Figure 8–31. (a) What initial speed \( v \) is required if the blocks \( m_1 = 2.4 \, \text{kg} \) and \( m_2 = 1.1 \, \text{kg} \) are to travel a distance \( d = 6.5 \, \text{cm} \) before coming to rest? Assume the coefficient of kinetic friction between \( m_1 \) and the tabletop is \( \mu_k = 0.25 \). (b) Is the work done on \( m_2 \) by the rope positive, negative, or zero? Explain. (c) Calculate the work done on \( m_2 \) by the rope.

96. ** IP Loop-the-Loop (a) A block of mass \( m \) slides from rest on a frictionless loop-the-loop track, as shown in Figure 8–32. What is the minimum release height, \( h \), required for the block to maintain contact with the track at all times? Give your answer in terms of the radius of the loop, \( r \). (b) Explain why the release height obtained in part (a) is independent of the block’s mass.

![Figure 8–32 Problem 96](image)
97. Figure 8-33 shows a 1.75-kg block at rest on a ramp of height $h$. When the block is released, it slides without friction to the bottom of the ramp, and then continues across a surface that is frictionless except for a rough patch of width 10.0 cm that has a coefficient of kinetic friction $\mu_k = 0.640$. Find $h$ such that the block's speed after crossing the rough patch is 3.50 m/s.

![Figure 8-33 Problem 97](image)

98. In Figure 8-34 a 1.2-kg block is held at rest against a spring with a force constant $k = 730$ N/m. Initially, the spring is compressed a distance $d$. When the block is released, it slides across a surface that is frictionless except for a rough patch of width 5.0 cm that has a coefficient of kinetic friction $\mu_k = 0.44$. Find $d$ such that the block's speed after crossing the rough patch is 2.3 m/s.

![Figure 8-34 Problem 98](image)

99. Using Work and Energy to Calculate Tension Consider the Atwood's machine shown in Figure 8-23, with $h = 1.2$m, $m_1 = 3.7$ kg, and $m_2 = 4.1$ kg. In this problem, we show how to calculate the tension in the rope using energy and work, rather than Newton's laws. (a) Is the change in mechanical energy for block 2 as it drops through the height $h$ positive, negative, or zero? Explain. (b) Use energy conservation applied to the entire system to calculate the change in mechanical energy for block 2 as it drops through the height $h$. (c) Use your answer to part (b), and the known drop height, to find the magnitude of the tension in the rope.

100. Treating the model wing as an ideal spring, what is the force constant of the hindwing when a force is applied to its tip?

A. 94 N/m  
B. 130 N/m  
C. 290 N/m  
D. 330 N/m

101. What is the force constant of the hindwing when a force is applied at two-thirds the distance from the base of the wing to the tip?

A. 94 N/m  
B. 130 N/m  
C. 290 N/m  
D. 330 N/m

102. Which of the wings is “stiffer”?

A. The hindwing.  
B. The forewing.  
C. Depends on where the force is applied.  
D. They are equally “stiff.”

103. How much energy is stored in the forewing when a force at the tip deflects it by 3.5 mm?

A. 0.766 mJ  
B. 49.0 mJ  
C. 0.219 J  
D. 1.70 kJ

PASSAGE PROBLEMS

810. The Flight of the Dragonflies

The story of the bat flies with a delicate inheritance from its ancient ancestors. The story of the bat touches the question of just what is needed to maintain the necessary flight ability.

Of all the animals you’re likely to see on a summer’s day, the most ancient is the dragonfly. In fact, the fossil record for dragonflies extends back over 250 million years, more than twice as long as for birds. Ancient dragonflies could be as large as a hawk, and were surely buzzing around the heads of both T. Rex and Triceratops.

Dragonflies belong to the order Odonata (“toothed jaws”) and the suborder Anisoptera (“different wings”), a reference to the fact that their hindwings are wider front-to-back than their forewings. (Damselsflies, in contrast, have forewings and hindwings that are the same.) Although ancient in their lineage, dragonflies are the fastest flying and most acrobatic of all insects; some of their maneuvers subject them to accelerations as great as 20g.

The properties of dragonfly wings, and how they account for such speed and mobility, have been of great interest to biologists. Figure 8-35 (a) shows an experimental setup designed to measure the force constant of Plexiglas models of wings, which are used in wind tunnel tests. A downward force is applied to the model wing at the tip (1 for hindwing, 2 for forewing) or at two-thirds the distance to the tip (3 for hindwing, 4 for forewing). As the force is varied in magnitude, the resulting deflection of the wing is measured. The results are shown in Figure 8-35 (b). Notice that significant differences are seen between the hindwings and forewings, as one might expect from their different shapes.

![Figure 8-35 Problems 100, 101, 102, and 103](image)

104. Referring to Example 8-8 Consider a spring with a force constant of 955 N/m. (a) Suppose the mass of the block is 1.70 kg, but its initial speed can be varied. What initial speed is required to give a maximum spring compression of 4.00 cm? (b) Suppose the initial speed of the block is 1.09 m/s, but its mass can be varied. What mass is required to give a maximum spring compression of 4.00 cm?

105. Referring to Example 8-8 Suppose the block is released from rest with the spring compressed 5.00 cm. The mass of the block is 1.70 kg and the force constant of the spring is 955 N/m. (a) What is the speed of the block when the spring expands to a compression of only 2.50 cm? (b) What is the speed of the block after it leaves the spring?

106. Referring to Example 8-10 Suppose we would like the landing speed of block 2 to be increased to 1.50 m/s. (a) Should the coefficient of kinetic friction between block 1 and the tabletop be increased or decreased? (b) Find the required coefficient of kinetic friction for a landing speed of 1.50 m/s. Note that $m_1 = 2.40$ kg, $m_2 = 1.80$ kg, and $d = 0.500$ m.