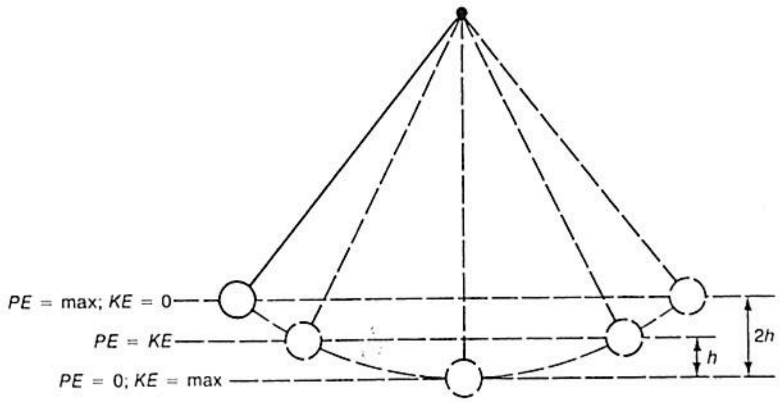


Figure 2-3. The relationship between potential and kinetic energy for an ideal pendulum.

The preceding discussion assumes that there is no friction or other non-conservative force acting. In reality, two objects in contact and moving relative to one another experience frictional force opposing the motion. The direction of the frictional force is always opposite to the direction of motion of the moving object.

The effect of this force is to convert some or all of the kinetic energy of the moving object into potential or kinetic energy of the component particles of the object. The energy of these particles is called the **internal energy** of the object. The increase of internal energy usually appears as an increase in temperature of the objects in contact. Since friction does work on objects in motion, tending to increase their internal energy at the expense of their kinetic energy, this amount of work must be taken into account in applying the law of conservation of energy.

PRACTICAL APPLICATION

A space vehicle reentering the atmosphere is slowed for landing by air friction. Some of the kinetic energy of the vehicle is changed to work done against the air friction, and this work is converted to heat. The vehicle must have a heat-resistant surface or shield to protect it against destruction by the high temperatures that result. ■

QUESTIONS

1. The work required to raise a 10.-kilogram box from the surface of the earth to a height of 5.0 meters is (1) 50. J (2) 100 J (3) 200 J (4) 490 J

2. The work done in accelerating an object along a frictionless horizontal surface is equal to the object's change in (1) momentum (2) velocity (3) potential energy (4) kinetic energy

3. Two objects unequal in mass falling freely from the same point above the earth's surface will experience the same (1) acceleration (2) decrease in potential energy (3) increase in kinetic energy (4) increase in momentum

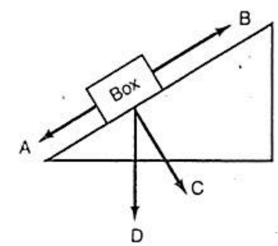
4. A 20.-kilogram object is moved a distance of 6.0 meters by a net force of 50. newtons. The total work done is (1) 120 J (2) 300 J (3) 420 J (4) 1,000 J

5. A 2-kilogram object is thrown vertically upward with an initial kinetic energy of 400 joules. The object will rise to a height of approximately (1) 10 m (2) 20 m (3) 400 m (4) 800 m

6. Which is a scalar quantity? (1) acceleration (2) momentum (3) force (4) energy

7. A simple pendulum whose mass is 1.00 kilogram swings to a maximum height of 0.200 meter above its lowest point. Neglecting friction, the kinetic energy of the pendulum bob at the lowest point in its swing is (1) 0.980 J (2) 1.96 J (3) 9.80 J (4) 19.6 J

8. A box is sliding down an inclined plane as shown. The force of friction is directed toward point
(1) *A*
(2) *B*
(3) *C*
(4) *D*



9. A bullet fired from a rifle emerges with a kinetic energy of 2,400 joules. Neglecting friction, if the barrel of the rifle is 0.50 meter long, the average force on the bullet in the barrel is approximately (1) 600 N (2) 1,200 N (3) 2,400 N (4) 4,800 N

10. Which is a vector quantity? (1) power (2) weight (3) energy (4) mass

11. The work required to lift a 50.-newton box a vertical distance of 5.0 meters is (1) 10. J (2) 45 J (3) 55 J (4) 250 J

12. If an object weighing 1.00 newton falls a vertical distance of 4.00 meters, the object's loss in potential energy is (1) 1.00 J (2) 9.80 J (3) 39.2 J (4) 4.00 J

13. What is the amount of work done when a force of 5 newtons moves a 10-kilogram mass a horizontal distance of 4 meters? (1) 5 J (2) 20 J (3) 40 J (4) 50 J

14. A 2.00-kilogram mass that is 15.0 meters above the ground has a potential energy of 294 joules. After falling 5.0 meters, the potential energy of the mass, with respect to the ground, will be (1) 49.0 J (2) 98.0 J (3) 196 J (4) 245 J

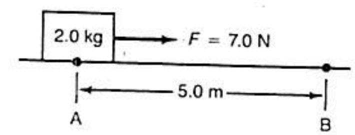
15. Which is a unit of power?

(1) joule (2) $\frac{\text{joule}}{\text{second}}$ (3) $\frac{\text{kilogram} \cdot \text{meter}}{\text{second}}$ (4) $\frac{\text{newton} \cdot \text{meter}^2}{\text{second}}$

16. At a height of 10. meters above the earth's surface, the potential energy of a 2.0-kilogram mass is 196 joules. After the mass, which starts from rest, has fallen 5.0 meters, its kinetic energy will be approximately (1) 200 J (2) 150 J (3) 100 J (4) 50 J
17. If the kinetic energy of an object is 16 joules when its speed is 4.0 meters per second, then the mass of the object is (1) 0.50 kg (2) 2.0 kg (3) 8.0 kg (4) 4.0 kg
18. A 10.-kilogram mass rests on a horizontal frictionless table. How much energy is needed to accelerate the mass from rest to a speed of 5.0 meters per second? (1) 25 J (2) 125 J (3) 3,125 J (4) 6,250 J
19. A force of 10 newtons is required to keep an object moving at a constant speed of 5 meters per second. The power used is (1) 0.5 W (2) 2 W (3) 5 W (4) 50 W
20. Which of these is a vector quantity? (1) velocity (2) speed (3) time (4) work
21. A net force of 9.0 newtons acts on an object through a distance of 3.0 meters. The work done on the object is (1) 27 J (2) 81 J (3) 98 J (4) 120 J
22. A 5.0-kilogram mass is raised 2.0 meters above a laboratory table. The potential energy of the mass with respect to the table is (1) 10. J (2) 50. J (3) 98 J (4) 120 J
23. A mass of 2.0 kilograms dropped from a height of 10. meters will strike the ground with a kinetic energy of approximately (1) 1.0×10^1 J (2) 2.0×10^1 J (3) 1.0×10^2 J (4) 2.0×10^2 J
24. As a stone thrown vertically upward rises, there is an increase in the stone's (1) weight (2) kinetic energy (3) potential energy (4) total energy
25. A wooden box is dragged along a horizontal floor toward the east. The direction of friction on the box is (1) up (2) down (3) east (4) west
26. One kilogram · meter squared per second squared is equivalent to one (1) newton (2) joule (3) watt (4) ampere
27. A box whose mass is 2 kilograms is pushed across a frictionless horizontal floor a distance of 3 meters with a force of 10 newtons. The increase in the potential energy of the box is (1) 0 J (2) 2 J (3) 30 J (4) 60 J
28. An elevator weighing 2.5×10^4 newtons is raised to a height of 10. meters. Neglecting friction, the work done on the elevator is (1) 2.5×10^4 J (2) 2.5×10^5 J (3) 2.5×10^3 J (4) 7.5×10^4 J
29. As a ball falls freely toward the earth, its kinetic energy (1) decreases (2) increases (3) remains the same
30. As the time required for a person to run up a flight of stairs increases, the power developed by the person (1) decreases (2) increases (3) remains the same
31. As a satellite in orbit moves from a distance of 300 kilometers to a distance of 160 kilometers above the earth, the kinetic energy of the satellite (1) decreases (2) increases (3) remains the same

32. A pendulum is set into motion to oscillate freely. As the pendulum's displacement from its rest position increases, its potential energy with respect to the earth (1) decreases (2) increases (3) remains the same
33. As a bullet shot vertically upward rises, its kinetic energy (1) decreases (2) increases (3) remains the same
34. As the time required to lift a 60-kilogram object 6 meters increases, the work required to lift the object (1) decreases (2) increases (3) remains the same
35. As a ball thrown vertically upward rises, its total energy (neglecting friction) (1) decreases (2) increases (3) remains the same
36. As the kinetic energy of a bullet in a rifle barrel increases, its momentum (1) decreases (2) increases (3) remains the same
37. As the time required for accomplishing a given amount of work decreases, the rate at which energy is expended (1) decreases (2) increases (3) remains the same
38. As a mass falls freely in a uniform gravitational field, the total mechanical energy of the mass (1) decreases (2) increases (3) remains the same

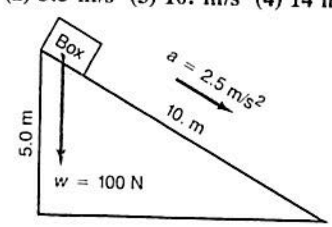
39–43. Base your answers to Questions 39 through 43 on the following information.



As shown in the diagram, a 2.0-kilogram mass is moved at a constant speed from point A to point B on a horizontal surface. The distance from A to B is 5.0 meters. The applied force, F, is 7.0 newtons.

39. The force of friction acting on the mass is (1) 0.0 N (2) 1.4 N (3) 7.0 N (4) 35 N
40. When the mass moves from A to B, its increase in kinetic energy is (1) 0.0 J (2) 10. J (3) 14 J (4) 35 J
41. If energy is transferred at the rate of 15 watts, the work done during 1.0 second is (1) 7.5 J (2) 15 J (3) 30. J (4) 35 J
42. While being moved from point A to point B, the kinetic energy of the mass (1) increases (2) decreases (3) remains the same
43. If the surface were frictionless, the 7.0-newton force would cause the block to accelerate at (1) 2.5 m/s^2 (2) 3.5 m/s^2 (3) 10. m/s^2 (4) 14 m/s^2

44–48. Base your answers to Questions 44 through 48 on the following information.



An inclined plane 10. meters long is elevated 5.0 meters at one end as shown in the diagram. Starting from rest at the top of the incline, a box weighing 100 newtons accelerates at a rate of 2.5 meters per second squared along the plane.

44. The potential energy of the box at the top of the incline was (1) 1,000 J (2) 500 J (3) 50 J (4) 0 J

45. How long will it take the box to reach the bottom of the incline? (1) 2.8 s (2) 2.0 s (3) 4.6 s (4) 4.0 s

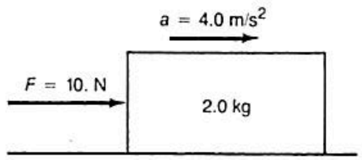
46. What is the approximate mass of the box? (1) 400 kg (2) 100 kg (3) 40 kg (4) 10 kg

47. If there is no friction as the box slides down the incline, the sum of its potential and kinetic energies will (1) decrease (2) increase (3) remain the same

48. As the box slides down the incline, its momentum will (1) decrease (2) increase (3) remain the same

49–53. Base your answers to Questions 49 through 53 on the following information.

A horizontal force of 10. newtons accelerates a 2.0-kilogram block from rest along a level table as shown, at a rate of 4.0 meters per second squared.



49. The work done in moving the block 8.0 meters is (1) 8.0 J (2) 20. J (3) 80. J (4) 800 J

50. When the speed of the block is 8.0 meters per second, its kinetic energy is (1) 8.0 J (2) 16 J (3) 64 J (4) 80. J

51. The time required for the block to attain a speed of 20. meters per second is (1) 1.0 s (2) 2.0 s (3) 5.0 s (4) 4.0 s

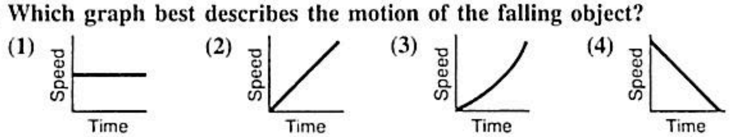
52. What is the frictional force retarding the forward motion of the block? (1) 8.0 N (2) 2.0 N (3) 10. N (4) 12 N

53. If there were no friction between the block and the table, the acceleration of the block would be (1) 20. m/s^2 (2) 9.8 m/s^2 (3) 5.0 m/s^2 (4) 4.0 m/s^2

54–58. Base your answers to Questions 54 through 58 on the information below.

A 6.0-kilogram object falls freely from rest for 5.0 meters and strikes the ground.

54. Which graph best describes the motion of the falling object?



55. The speed of the object just before it strikes the ground is closest to (1) 140 m/s (2) 30. m/s (3) 10. m/s (4) 5.0 m/s

56. The time for the object to fall is closest to (1) 0.10 s (2) 1.0 s (3) 10. s (4) 15 s

57. The kinetic energy of the mass just before it strikes the ground is closest to (1) 1.0 J (2) 30. J (3) 50. J (4) 300 J

58. The weight of the object is closest to (1) 1.0 N (2) 6.0 N (3) 30. N (4) 60. N

59–63. Base your answers to Questions 59 through 63 on the statement below.

A 2.00-kilogram rock, which originally rested on the edge of a cliff 100. meters high, fell to the base of the cliff.

59. Before falling, the rock's potential energy with respect to the base of the cliff was (1) 50.0 J (2) 980. J (3) 1,960 J (4) 6,400 J

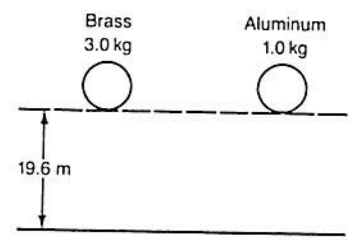
60. What is the kinetic energy of the falling rock 50. meters above the base of the cliff? (1) 25 J (2) 490 J (3) 980 J (4) 3,200 J

61. What is the momentum of the rock when its speed is 10.0 meters per second? (1) 10.0 kg · m/s (2) 20.0 kg · m/s (3) 50.0 kg · m/s (4) 100. kg · m/s

62. The speed of the rock an instant before it hits the base of the cliff is approximately (1) 22 m/s (2) 31 m/s (3) 44 m/s (4) 62 m/s

63. Neglecting air resistance, the total mechanical energy of the rock at any time during its fall is equal to which of the following? (1) its potential energy minus its kinetic energy (2) its kinetic energy minus its potential energy (3) zero (4) the sum of its potential and kinetic energies

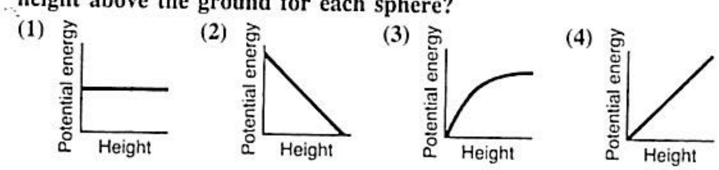
64–66. Base your answers to Questions 64 through 66 on the diagram at the right, which shows a 1.0-kilogram aluminum sphere and a 3.0-kilogram brass sphere. Each of the spheres has the same diameter, and each is 19.6 meters above the ground. Both spheres are allowed to fall freely. (Neglect the effects of air resistance.)



64. Both spheres are released at the same instant. They will reach the ground at (1) the same time, but with different speeds (2) the same time and with the same speeds (3) different times, but with the same speeds (4) different times and with different speeds

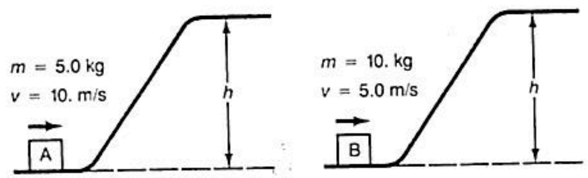
65. If the spheres are 19.6 meters above the ground, the time required for the aluminum sphere to reach the ground is (1) 1.0 s (2) 2.0 s (3) 8.0 s (4) 4.0 s

66. Which graph shows the relationship between the potential energy and height above the ground for each sphere?

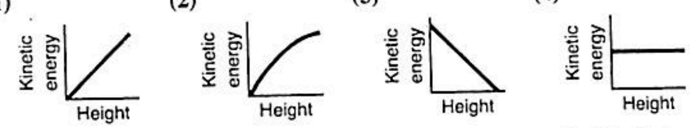


67–71. Base your answers to Questions 67 through 71 on the following information.

As shown in the diagrams, object A has a mass of 5.0 kilograms and a speed of 10. meters per second at the foot of a frictionless hill. Object B has a mass of 10. kilograms and a speed of 5.0 meters per second at the foot of an identical hill.



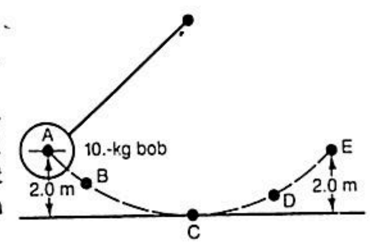
67. In the positions shown in the diagrams, how does the kinetic energy of object A compare with the kinetic energy of object B? (1) It is one-fourth as great. (2) It is one-half as great. (3) It is the same. (4) It is twice as great.
68. In the positions shown in the diagrams, how does the momentum of object A compare with the momentum of object B? (1) It is one-fourth as great. (2) It is one-half as great. (3) It is the same. (4) It is twice as great.
69. Which graph best represents the relationship between height up the hill and kinetic energy for each of the masses?



70. At the top of the hill, the force of gravity on A, compared with that on B, will be (1) less (2) greater (3) the same
71. At the top of the hill, the potential energy of A, compared with that of B, will be (1) less (2) greater (3) the same

72–77. Base your answers to Questions 72 through 77 on the following information.

A pendulum with a 10.-kilogram bob is released at point A and allowed to swing without friction, as shown in the diagram at the right.

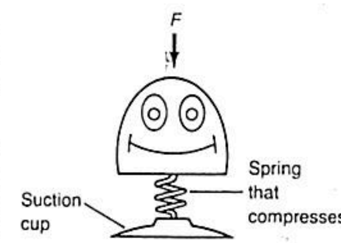


72. What is the weight of the bob? (1) 0.10 N (2) 0.98 N (3) 10. N (4) 98 N
73. The force of the string on the bob is greatest at point (1) A (2) B (3) C (4) D

74. What is the velocity of the bob at point E? (1) 0.0 m/s (2) 2.0 m/s (3) 6.3 m/s (4) 9.8 m/s
75. The potential energy of the bob at point A compared to its potential energy at point C is approximately (1) 20 J (2) 40 J (3) 200 J (4) 400 J
76. In moving from point A to point B, the bob's total mechanical energy (1) decreases (2) increases (3) remains the same
77. As the bob moves from point C to point D, the kinetic energy of the bob (1) decreases (2) increases (3) remains the same

78–80. Base your answers to Questions 78 through 80 on the following information and the diagram at the right.

A toy figure is situated on top of a spring attached to a suction cup. The spring is compressed 0.020 meter by a force of 0.30 newton.



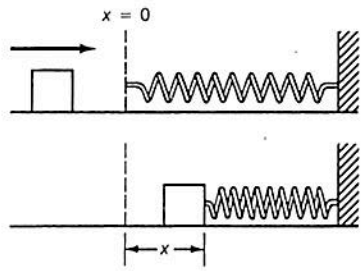
78. What is the spring constant for this spring? (1) 0.0060 N/m (2) 9.8 N/m (3) 15 N/m (4) 750 N/m
79. The work done in compressing the spring is approximately (1) 3.0×10^{-3} J (2) 2.0×10^{-1} J (3) 3.0 J (4) 1.5×10^{1} J
80. The potential energy stored in the compressed spring is approximately (1) 3.0×10^{-3} J (2) 2.0×10^{-1} J (3) 3.0 J (4) 1.5×10^{1} J
81. A force is applied to a given spring causing it to stretch a distance x. If the applied force is halved, the elongation of the spring will be (1) halved (2) doubled (3) quartered (4) quadrupled
82. A force is applied to a spring causing it to stretch. If the applied force is doubled, and the elasticity of the spring is not exceeded, the potential energy stored in the spring will be (1) halved (2) doubled (3) quartered (4) quadrupled
83. A spring having a spring constant k is cut in half. Each of the newly formed springs has a spring constant that is equal to (1) $k/2$ (2) $2k$ (3) k (4) $4k$
84. If the distance a spring is stretched is doubled, and the elastic limit is not exceeded, the potential energy stored in the spring is (1) halved (2) doubled (3) quartered (4) quadrupled
85. A 0.10-kilogram ball that is dropped to the floor from a height of 2.0 meters then rebounds to a height of 1.8 meters. The increase in internal energy for the system is approximately (1) 1.8 J (2) 2.0 J (3) 0.10 J (4) 0.20 J
86. A 2.00-kilogram mass suspended from a spring causes the spring to elongate 1.00×10^{-1} meter. The spring constant of the spring is (1) 0.200 N/m (2) 1.96 N/m (3) 49.0 N/m (4) 196 N/m

87. A given spring has a spring constant of 400 newtons per meter. How much work is done in stretching the spring a distance of 0.020 meter from its equilibrium position?
(1) 8.0 J (2) 8.0×10^{-1} J (3) 8.0×10^{-2} J (4) 8.0×10^{-3} J

88. A spring having a spring constant of 400 newtons per meter is stretched to a distance of 0.020 meter from its equilibrium position. How much work is done to stretch the spring an additional 0.020 meter? (1) 0.080 J (2) 0.16 J (3) 0.24 J (4) 0.32 J

89–93. Base your answers to Questions 89 through 93 on the information given below.

A block that is sliding on a frictionless horizontal surface collides with a spring, as is illustrated in the diagram at the right.



89. During the interval of collision, the speed of the block (1) decreases (2) increases (3) remains the same

90. During the interval of collision, the potential energy of the spring (1) decreases (2) increases (3) remains the same

91. As the block compresses the spring, the spring constant for the spring (1) decreases (2) increases (3) remains the same

92. As the block compresses the spring, the total mechanical energy of the system (1) decreases (2) increases (3) remains the same

93. If the initial speed of the block had been greater, the maximum compression of the spring would have been (1) less (2) greater (3) the same

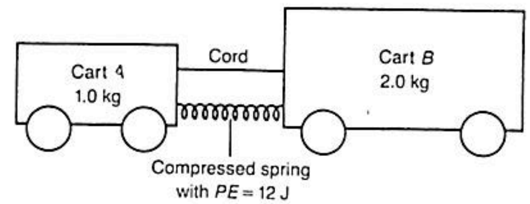
Sample Problem

Cart A of 1.0-kilogram mass and cart B of 2.0-kilogram mass are placed on a frictionless table as shown in the diagram below. A spring of negligible mass is compressed between the two carts until the spring's potential energy is 12 joules. When the cord is cut the spring will force the carts apart.

(a) Compare the following quantities while the spring is pushing the carts apart:
   (1) The forces acting on the two carts.
   (2) The change in momentum of the two carts.
   (3) The total initial momentum and final momentum of the two carts.
   (4) The acceleration of the two carts.

(b) Calculate the final velocity of cart A.

(c) Determine the ratio of the maximum kinetic energy of cart A to that of cart B.



Solution

(a) (1) The forces are equal in magnitude and opposite in direction.
   (2) The change in momentum is equal in magnitude and opposite in direction for the two carts at all times.
   (3) The total momentum is zero at all times.
   (4) The acceleration of cart A will be twice that of cart B (because the forces are equal and the mass of A is ½ that of B) and opposite in direction.

(b) From the conservation of momentum, the initial momentum of the system must equal the final momentum of the system. Because the carts are initially at rest, their initial momentum is zero. Therefore, their total momentum must remain zero:

$$m_A v_A + m_B v_B = 0$$

$$m_B v_B = -m_A v_A$$

$$v_B = -\frac{m_A v_A}{m_B}$$

$$v_B = -\frac{(1.0 \text{ kg}) v_A}{2.0 \text{ kg}} = -\tfrac{1}{2} v_A$$