TOPIC 3

Energy

How Scientists Study Energy

Does a power company sell power?

Both energy and work are equal to the product of power and time. Power is the time rate of doing work. A power company is always ready to supply electrical energy to its customers, but unless the energy is used, no work is done, and thus no energy is consumed. A 60-watt incandescent lamp operating for two seconds consumes twice as much energy as the same lamp operating for one second. The power company charges its customers for watt•seconds of energy or kilowatt•hours of energy rather than watts of power. One kilowatt•hour is equal to 1000 watts $\times$ 3600 seconds or 3.6×10^6 joules of energy. The kilowatt•hour meter found in a home or place of business records the total energy used by the consumer.

TOPIC

3 Energy

Vocabulary

battery	internal energy	potential energy
compression	joule	power
elastic potential energy	kinetic energy	simple pendulum
electromagnetic energy	law of conservation of energy	spring constant
elongation	mechanical energy	thermal energy
energy	motor	total energy
generator	nonideal mechanical system	watt
gravitational potential energy	nuclear energy	work
ideal mechanical system	photocell	

Work and Energy

Energy is the ability to do work. Energy is a scalar quantity. When work is done on or by a system, the total energy of the system is changed.

Work

Work is the transfer of energy to an object when the object moves due to the application of a force. The force can be entirely in the direction of the object's motion or have a component in the direction of the motion. Work is a scalar quantity. The amount of work done, W, is equal to the product of the force, F, along the direction of displacement, and the displacement d, of the object. The work done on the object produces a change in the object's total energy, ΔE_T:

$$W = Fd = \Delta E_T$$ Ⓡ

The force F is in newtons and the displacement d is in meters. Thus, the work W or change in total energy ΔE_T can be expressed with the unit newton · meter. However, notice in the expressions below that 1 newton · meter equals 1 joule.

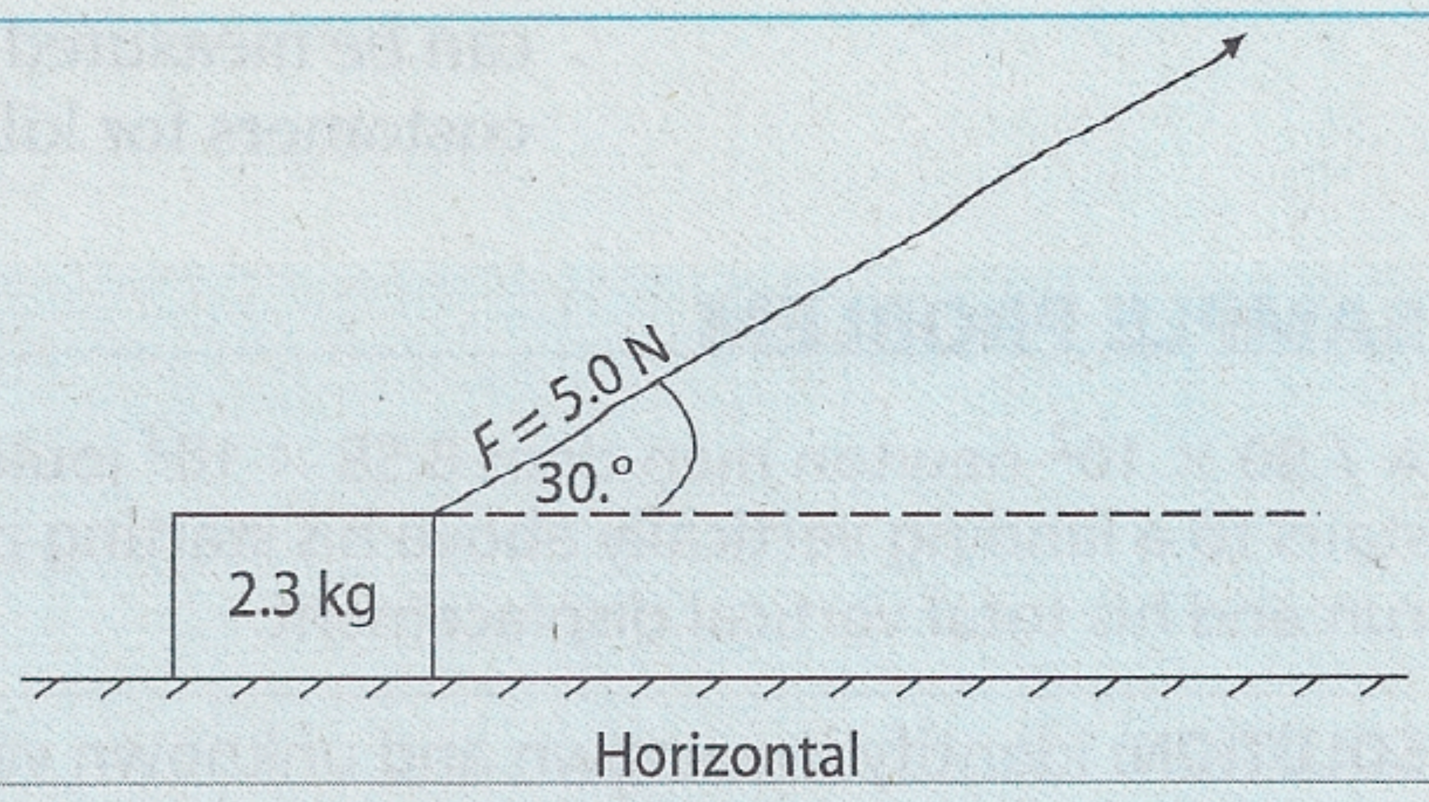
$$1 \text{ newton} \cdot \text{meter} = (1 \text{ kilogram} \cdot \text{meter/second}^2)\ (\text{meter})$$
$$1 \text{ newton} \cdot \text{meter} = 1 \text{ kilogram} \cdot \text{meter}^2/\text{second}^2 = 1 \text{ joule}$$

The **joule,** J, is a derived unit equal to the work done on an object when a force of one newton produces a displacement of one meter. Note that the amount of work done is independent of the time the force acts on the object.

When a force is applied to a mass, but the mass does not move, no work is done. If a student was to hold an object at a constant height above the ground, no work would be done no matter how heavy the object might be and how much effort the student expended.

SAMPLE PROBLEM

A 2.3-kilogram block rests on a horizontal surface. A constant force with a magnitude of 5.0 newtons is applied to the block at an angle of 30.° to the horizontal, as shown in the diagram. The diagram is drawn to scale.



SOLUTION: Calculate the work done in moving the block 2.0 meters to the right along the surface.

Known	*Unknown*
$F = 5.0$ N	$F_x = ?$ N
$m = 2.3$ kg	$W = ?$ J
$d = 2.0$ m	

1. Find the component of the applied force that is in the *x*-direction, that is, in the direction of the displacement. There are two ways to do this.

(a) Use the trigonometric relationship $F_x = F\cos\theta$. Substitute the known values and solve.

$F_x = (5.0 \text{ N})(\cos 30.°) = 4.3 \text{ N}$

(b) Determine the scale in the diagram: 1.0 cm = 1.0 N. Project the 5.0-newton force onto the horizontal dashed line in the diagram and measure the line segment. This is the component of the applied force in the direction of motion, 4.3 N.

2. Use the formula that defines work to calculate the work done.

$W = Fd$

3. Substitute the known values and solve.

$W = (4.3 \text{ N})(2.0 \text{ m}) = 8.6 \text{ J}$

Power The rate at which work is done is a scalar quantity called **power.** By definition, power P is given by the formula $P = \frac{W}{t}$. However, $W = Fd$ and $\overline{v} = \frac{d}{t}$. Therefore, the formula can be rewritten as follows:

$$P = \frac{W}{t} = \frac{Fd}{t} = F\overline{v}$$ (R)

F is the force applied to an object that causes it to move with an average speed $\overline{v}$. If work W is in joules and time t is in seconds, then power can be expressed in joules per second. One joule of work done per second equals one **watt,** W, the SI derived unit for power. If 1 watt = 1 joule/second and 1 joule = 1 kilogram · meter^2/second^2, then 1 watt = 1 kilogram · meter^2/second^2/second = 1 kilogram · meter^2/second^3.

(Do not confuse the symbol W, which is used for the *quantity* of work, with the abbreviation W for the *unit* watt.)

Because power is inversely proportional to time, the less time required to do a given amount of work, the greater the power developed. For example, as the length of time it takes a student to swim 25 meters decreases, the power developed by the student increases.

From the definition of power, $P = \frac{W}{t}$, it follows that $W = Pt$. Thus, one watt of power used for one second transfers one joule of energy or does one joule of work. One joule is equivalent to one watt · second, and energy can be measured in watt · seconds. Electric utility companies charge their customers for kilowatt · hours of energy rather than for watts of power.

SAMPLE PROBLEM

A 7.80×10^2-newton man does 8.58×10^3 joules of work in 12.3 seconds by running up three flights of stairs to a landing vertically above his starting point. Calculate the power developed by the man during his run and his total vertical displacement.

SOLUTION: Identify the known and unknown values.

Known	*Unknown*
$F_g = 7.80 \times 10^2$ N	$P = ?$ J/s or W
$W = 8.58 \times 10^3$ J	$d = ?$ m
$t = 12.3$ s	

1. Write the formula that defines power.

$$P = \frac{W}{t}$$

2. Substitute the known values and solve.

$$P = \frac{8.58 \times 10^3 \text{ J}}{12.3 \text{ s}} = 698 \text{ W}$$

3. To find the displacement, use the formula that defines work.

$$W = Fd$$

Solve the equation for d.

$$d = \frac{W}{F}$$

4. Substitute the known values and solve.

$$d = \frac{8.58 \times 10^3 \text{ J}}{7.80 \times 10^2 \text{ N}} = 11.0 \text{ m}$$

SAMPLE PROBLEM

A constant horizontal force of 6.0 newtons to the left is applied to a box on a counter to overcome friction. Calculate the power dissipated in moving the box 3.0 meters to the left along the counter in 1.5 seconds.

SOLUTION: Identify the known and unknown values.

Known	*Unknown*
$F = 6.0$ N	$P = ?$ W
$d = 3.0$ m	
$t = 1.5$ s	

1. Write the formula that defines power.

$$P = \frac{Fd}{t}$$

2. Substitute the known values and solve.

$$P = \frac{(6.0 \text{ N})(3.0 \text{ m})}{1.5 \text{ s}} = 12 \text{ W}$$

SAMPLE PROBLEM

In raising an object vertically at a constant speed of 2.0 meters per second, the power developed is 18 watts. Calculate the weight of the object.

SOLUTION: Identify the known and unknown values.

Known	*Unknown*
$v = 2.0$ m/s	$F_g = ?$ N
$P = 18$ W	

1. Write the formula for power.

$$P = F\overline{v}$$

2. Solve the equation for F.

$$F = \frac{P}{\overline{v}}$$

3. Substitute the known values and solve.

$$F = \frac{18 \text{ W}}{2.0 \text{ m/s}} = 9.0 \text{ N}$$

Because the object is raised at constant speed, it is in equilibrium. The force required to raise the object is equal in magnitude but opposite in direction to F_g, the weight of the object.

Review Questions

1. Which combination of units can be used to express work?
   (1) newton · second/meter
   (2) newton · meter/second
   (3) newton/meter
   (4) newton · meter

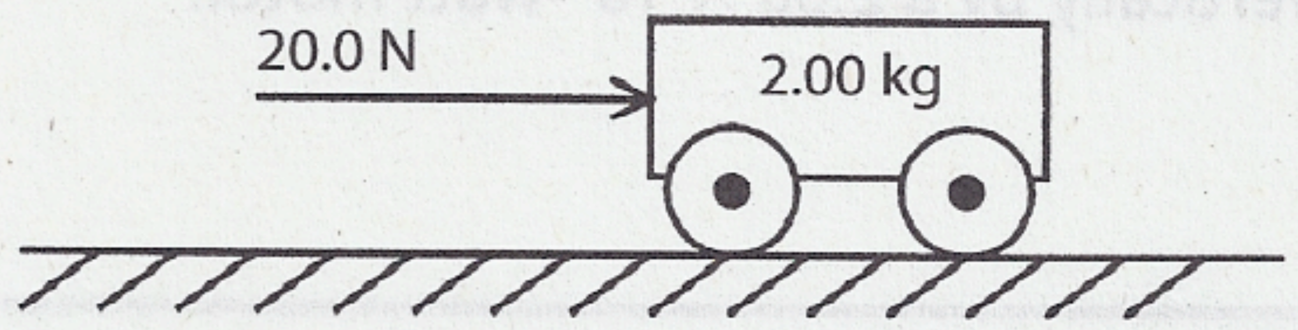
2. A jack exerts a vertical force of 4.5×10^3 newtons to raise a car 0.25 meter. How much work is done by the jack?
   (1) 5.6×10^{-5} J
   (2) 1.1×10^3 J
   (3) 4.5×10^3 J
   (4) 1.8×10^4 J

3. If a 2.0-kilogram mass is raised 0.050 meter vertically, the work done on the mass is approximately
   (1) 0.10 J
   (2) 0.98 J
   (3) 9.8 J
   (4) 40. J

4. A total of 640 joules of work is done on a 50.-kilogram object as it is moved 8.0 meters across a level floor by the application of a horizontal force. Determine the magnitude of the horizontal force applied to the object.

5. Work is being done when a force
   (1) acts vertically on a cart that can only move horizontally
   (2) is exerted by one team in a tug of war when there is no movement
   (3) is exerted while pulling a wagon up a hill
   (4) of gravitational attraction acts on a person standing on the surface of Earth

6. In the diagram below, a horizontal force with a magnitude of 20.0 newtons is used to push a 2.00-kilogram cart a distance of 5.00 meters along a level floor.



Determine the amount of work done on the cart.

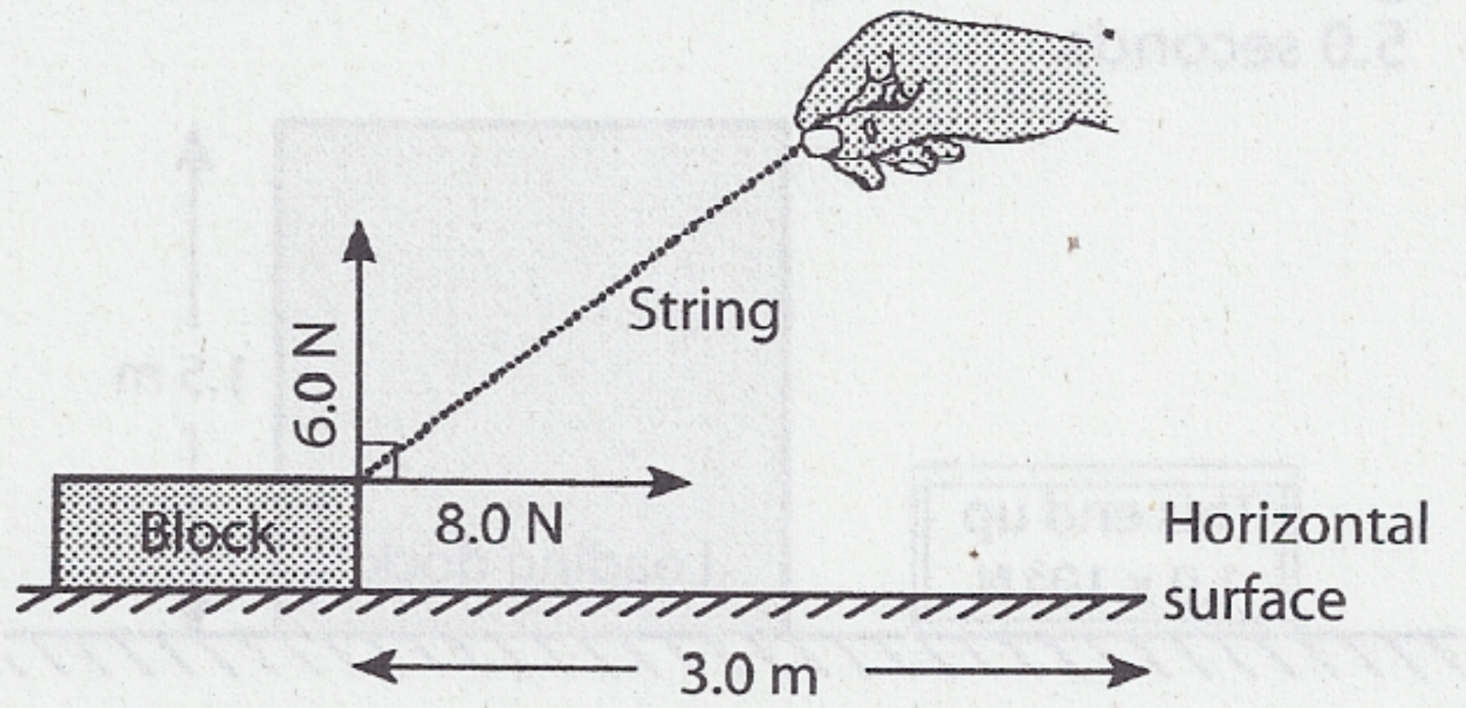
7. A constant force with a magnitude of 1.9×10^3 newtons is required to keep an automobile having a mass of 1.0×10^3 kilograms moving at a constant speed of 20. meters per second. The work done in moving the automobile a distance of 2.0×10^3 meters is
   (1) 2.0×10^4 J
   (2) 3.8×10^4 J
   (3) 2.0×10^6 J
   (4) 3.8×10^6 J

8. A student does 300. joules of work pushing a cart 3.0 meters due east and then does 400. joules of work pushing the cart 4.0 meters due north. The total amount of work done by the student is
   (1) 100. J (3) 700. J
   (2) 500. J (4) 2500 J

9. A constant horizontal force of 20.0 newtons east applied to a box causes it to move at a constant speed of 4.0 meters per second. Calculate how much work is done against friction on the box in 6.0 seconds.

10. A horizontal force with a magnitude of 3.0 newtons applied to a 7.0-kilogram mass moves the mass horizontally a distance of 2.0 meters. Determine the work done against gravity in moving the mass.

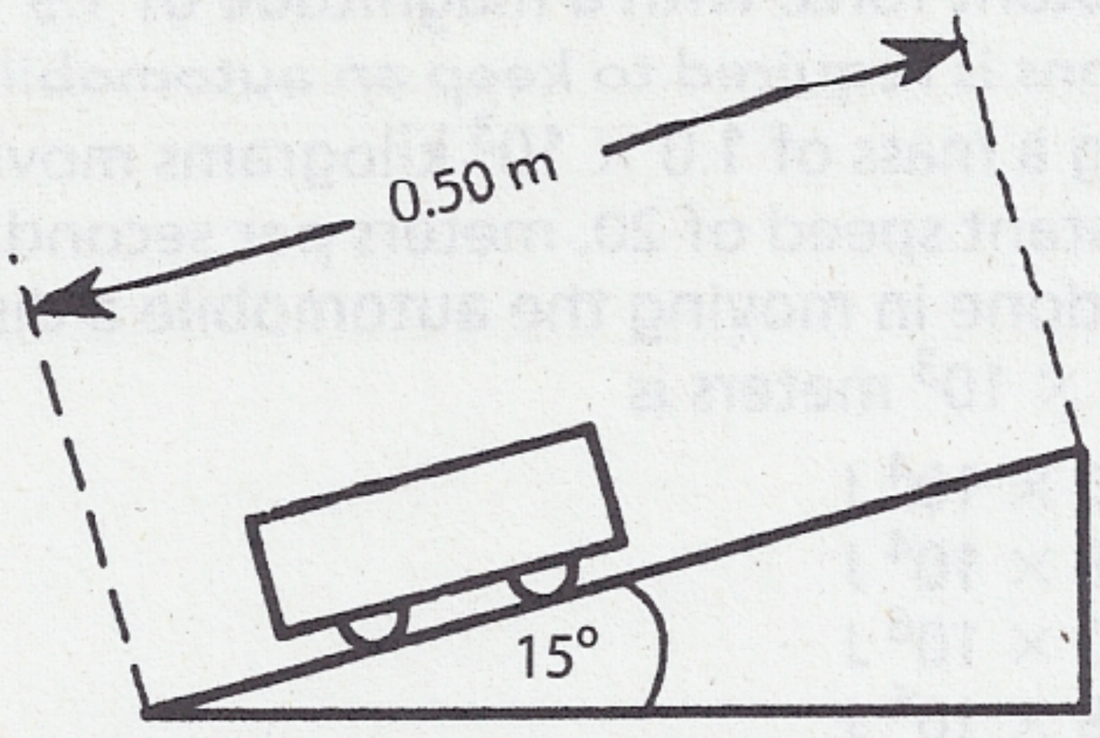
11. A student pulls a block along a horizontal surface at constant velocity. The diagram below shows the components of the force exerted on the block by the student.



Calculate the work done against friction.

12. A total of 8.0 joules of work is done when a constant horizontal force of 2.0 newtons to the left is used to push a 3.0-kilogram box across a counter top. Determine the total horizontal distance the box moves.

13. The diagram below shows a 9.8-newton cart being pulled 0.50 meter along a plane inclined at 15° to the horizontal. The amount of work required is 1.3 joules.



If the cart was raised 0.50 meter vertically instead of being pulled along the inclined plane, the amount of work done would be

(1) 0.0 J (2) 1.3 J (3) 4.9 J (4) 9.8 J

14. A crane raises a 200-newton weight to a height of 50 meters in 5 seconds. The crane does work at the rate of

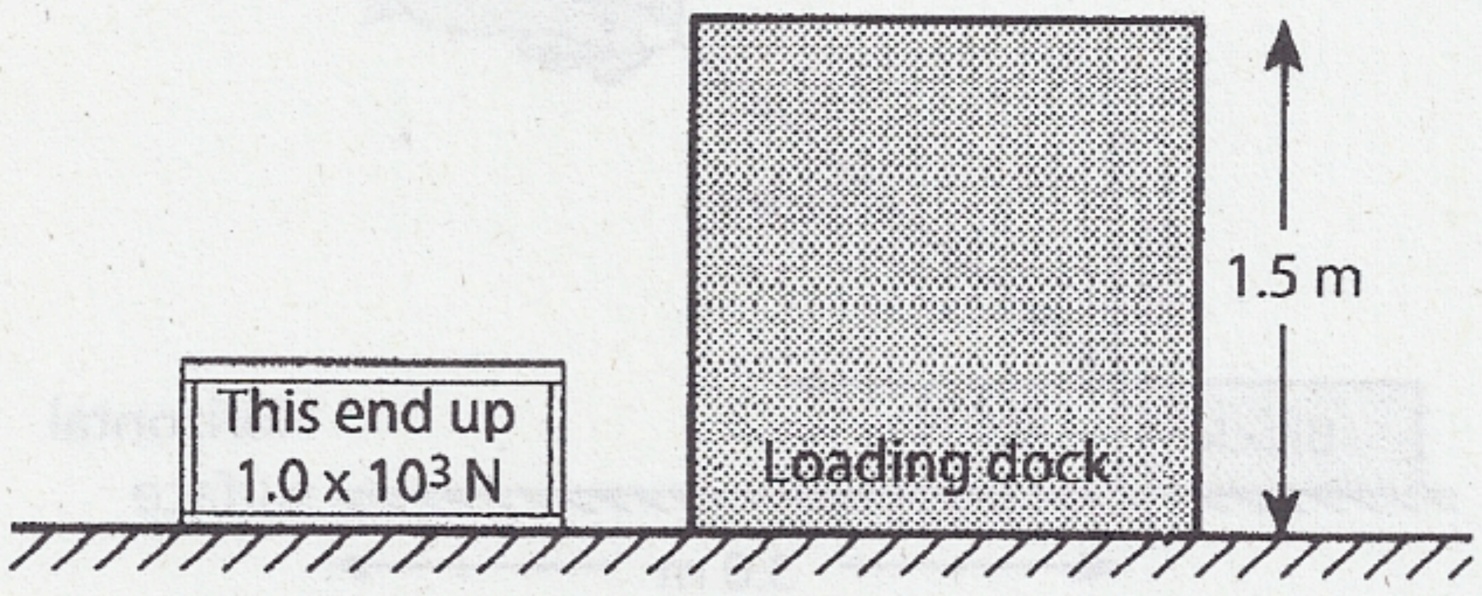
(1) 8×10^{-1} W (3) 2×10^{3} W
(2) 2×10^{1} W (4) 5×10^{4} W

15. What is the maximum amount of work that a 5000.-watt motor can do in 10. seconds?

(1) 5.0×10^{1} J (3) 5.0×10^{3} J
(2) 5.0×10^{2} J (4) 5.0×10^{4} J

16. An engine rated at 5.0×10^{4} watts exerts a constant force of 2.5×10^{3} newtons on a vehicle. Determine the average speed of the vehicle.

17. The diagram below shows a 1.0×10^{3}-newton crate to be lifted at constant speed from the ground to a loading dock 1.5 meters high in 5.0 seconds.



What power is required to lift the crate?

(1) 1.5×10^{3} W (3) 3.0×10^{2} W
(2) 2.0×10^{2} W (4) 7.5×10^{3} W

18. What is the average power developed by a motor as it lifts a 400-kilogram mass at a constant speed through a vertical distance of 10.0 meters in 8.0 seconds?

(1) 320 W (3) 4,900 W
(2) 500 W (4) 32,000 W

19. Determine the power developed by a man weighing 6.0×10^{2} newtons who climbs a rope at a constant speed of 2.0 meters per second.

20. Student *A* lifts a 40.-newton box from the floor to a height of 0.30 meter in 2.0 seconds. Student *B* lifts a 30.-newton box from the floor to a height of 0.40 meter in 4.0 seconds. Compared to student *A*, student *B* does

(1) less work but develops more power
(2) more work but develops less power
(3) the same work but develops less power
(4) the same work but develops more power

21. A 5.0×10^{2}-newton girl develops 250 watts of power as she runs up two flights of stairs to a landing a total of 5.0 meters vertically above her starting point. Calculate the time required for the girl to run up the stairs.

22. A motor having a maximum power rating of 8.1×10^{4} watts is used to operate an elevator with a weight of 1.8×10^{4} newtons. What is the maximum weight this motor can lift at an average speed of 3.0 meters per second?

(1) 6.0×10^{3} N (3) 2.4×10^{4} N
(2) 1.8×10^{4} N (4) 2.7×10^{4} N

23. A girl weighing 500. newtons takes 50.0 seconds to climb a flight of stairs 18 meters high. Calculate the girl's vertical power output.

24. If the time required for a student to swim 500. meters is doubled, the power developed by the student will be

(1) halved
(2) doubled
(3) quartered
(4) quadrupled

25. Calculate the average speed of a 4.0×10^{2}-newton weight being lifted vertically by a 2.00×10^{3}-watt motor.

Forms of Energy

As already noted, energy and work are related. The joule is the SI unit for both quantities, which are scalar. When one system does work on another system, the second system gains an amount of energy equal to the amount of work done on it. This process is called a transfer of energy.

Energy has many forms, including thermal, chemical, nuclear, electromagnetic, sound, and mechanical. Whatever its form, energy is measured by the amount of work it can do. **Thermal energy,** or heat, is the total kinetic energy possessed by the individual particles that comprise an object. (The term "thermal energy" is also used by nuclear physicists to describe the average kinetic energy, 0.025 electronvolt, possessed by neutrons at room temperature.)

Internal energy refers to the total potential energy and kinetic energy possessed by the particles that make up an object, but excludes the potential and kinetic energies of the system as a whole.

Nuclear energy is the energy released by nuclear fission, the division of a heavy atomic nucleus into parts of comparable mass, or nuclear fusion, the combining of two light nuclei to form a heavier nucleus.

Electromagnetic energy is the energy associated with electric or magnetic fields. Electromagnetic energy can take many forms, such as visible light, microwaves, and radio waves.

Devices for Converting Energy

A **photocell** (photovoltaic cell) is a device that converts light, a form of electromagnetic radiation, into electrical energy. A **generator** is a device that converts mechanical energy into electrical energy by rotating a large coil of wire in a magnetic field. On the other hand, a **motor** is a device that converts electrical energy into mechanical energy as a result of forces on a current-carrying conductor in a magnetic field. A **battery** is a direct-current voltage source that converts chemical, thermal, nuclear, or solar energy into electrical energy.

Potential Energy

The energy possessed by an object due to its position or condition is called **potential energy.** If there is no energy lost due to friction, the work done to bring the object to a different position or condition from its original condition or position is equal to the object's change in potential energy.

Gravitational Potential Energy If an object, originally at rest on Earth's surface, is lifted to some height, work is done *against* gravitational force. The work done in lifting the object to a height above Earth's surface is equal to the object's **gravitational potential energy** relative to Earth's surface. The work done is equal to the gravitational potential energy acquired by the object. If the object falls, work is done *by* gravity on the object, and the object loses gravitational potential energy. However, the work done by gravity on the object increases its energy of motion (kinetic energy) as the object's speed increases during its fall. This kinetic energy can, in turn, do an amount of work equal to the loss in gravitational potential energy.

Recall that work is described by the formula $W = Fd$. For a falling object, F equals F_g, the weight of the object given by the formula $F_g = mg$, and the displacement d corresponds to Δh, the change in height. Thus, the change in gravitational potential energy is given by the formula:

$$\Delta PE = mg\Delta h$$ Ⓡ

The mass m is in kilograms, g is the acceleration due to gravity in meters per second^2 (or gravitational field strength in newtons per kilogram), and Δh is the change in height of the mass in meters. Thus ΔPE, the change in gravitational potential energy, can be expressed in kilogram · meter^2 per second^2 or joules. The change in gravitational potential energy of an object equals the product of its weight, mg, and its vertical change in height. This formula is valid only for displacements that are small compared to Earth's radius, so that g can be considered constant.

SAMPLE PROBLEM

Calculate the gravitational potential energy with respect to the floor gained by a 2.00-kilogram object as a result of being lifted from the floor to the top of a 0.92-meter high table.

SOLUTION: Identify the known and unknown values.

Known	*Unknown*
$m = 2.00$ kg	$\Delta PE = ?$ J
$h = 0.92$ m	
$g = 9.81$ m/s^2	

1. Write the formula for gravitational potential energy.

$\Delta PE = mg\Delta h$

2. Substitute the known values and solve.

$\Delta PE = (2.00 \text{ kg})(9.81 \text{ m/s}^2)(0.92 \text{ m}) = 18 \text{ J}$

SAMPLE PROBLEM

A 15.3-newton book gains 18.4 joules of gravitational potential energy with respect to the floor as a result of being lifted from the floor to a shelf. Calculate the height of the shelf above the floor.

SOLUTION: Identify the known and unknown values.

Known	*Unknown*
$F_g = 15.3$ N	$\Delta h = ?$ m
$\Delta PE = 18.4$ J	

1. Write the formula for gravitational potential energy and solve for Δh.

$\Delta PE = mg\Delta h$

$\Delta h = \dfrac{\Delta PE}{mg}$

2. Substitute the known values and solve. The weight of the object, F_g, equals mg.

$\Delta h = \dfrac{18.4 \text{ J}}{15.3 \text{ N}} = 1.20 \text{ m}$

Review Questions

26. Which term identifies a scalar quantity?
(1) force
(2) energy
(3) displacement
(4) velocity

27. Energy is measured in the same units as
(1) force (2) momentum (3) power (4) work

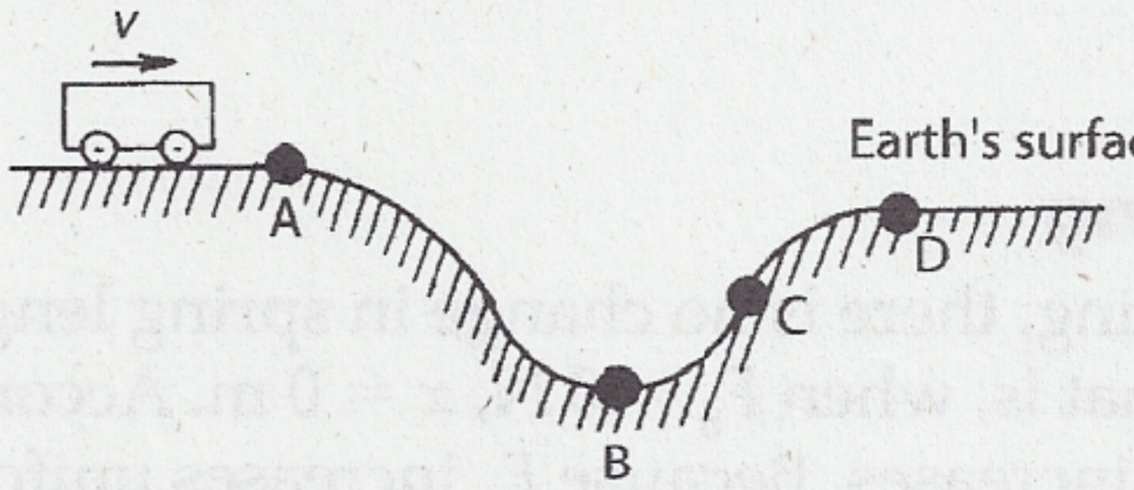
28. Which quantity and unit are correctly paired?
(1) velocity; m/s^2
(2) momentum; $kg \cdot m/s^2$
(3) energy; $kg \cdot m^2/s^2$
(4) work; kg/m

29. A unit for gravitational potential energy is the
(1) watt
(2) joule
(3) newton
(4) kilogram · meter/second

30. Which mass has the greatest gravitational potential energy with respect to the floor?
(1) a 50.-kg mass resting on the floor
(2) a 2.0-kg mass 10. m above the floor
(3) a 10.-kg mass 2.0 m above the floor
(4) a 6.0-kg mass 5.0 m above the floor

31. As an object slides across a rough horizontal surface, what happens to the object's gravitational potential energy with respect to the surface and speed?
(1) Both gravitational potential energy and speed decrease.
(2) Gravitational potential energy decreases and speed remains the same.
(3) Gravitational potential energy remains the same and speed decreases.
(4) Both gravitational potential energy and speed remain the same.

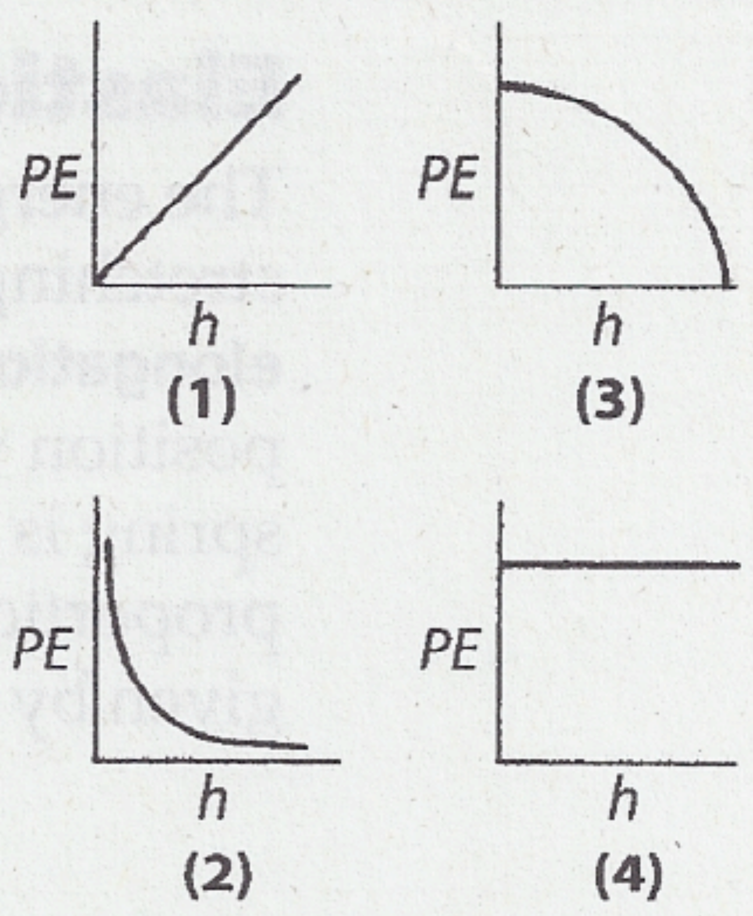
32. The diagram below represents a cart traveling with initial speed *v* from left to right along a frictionless surface.



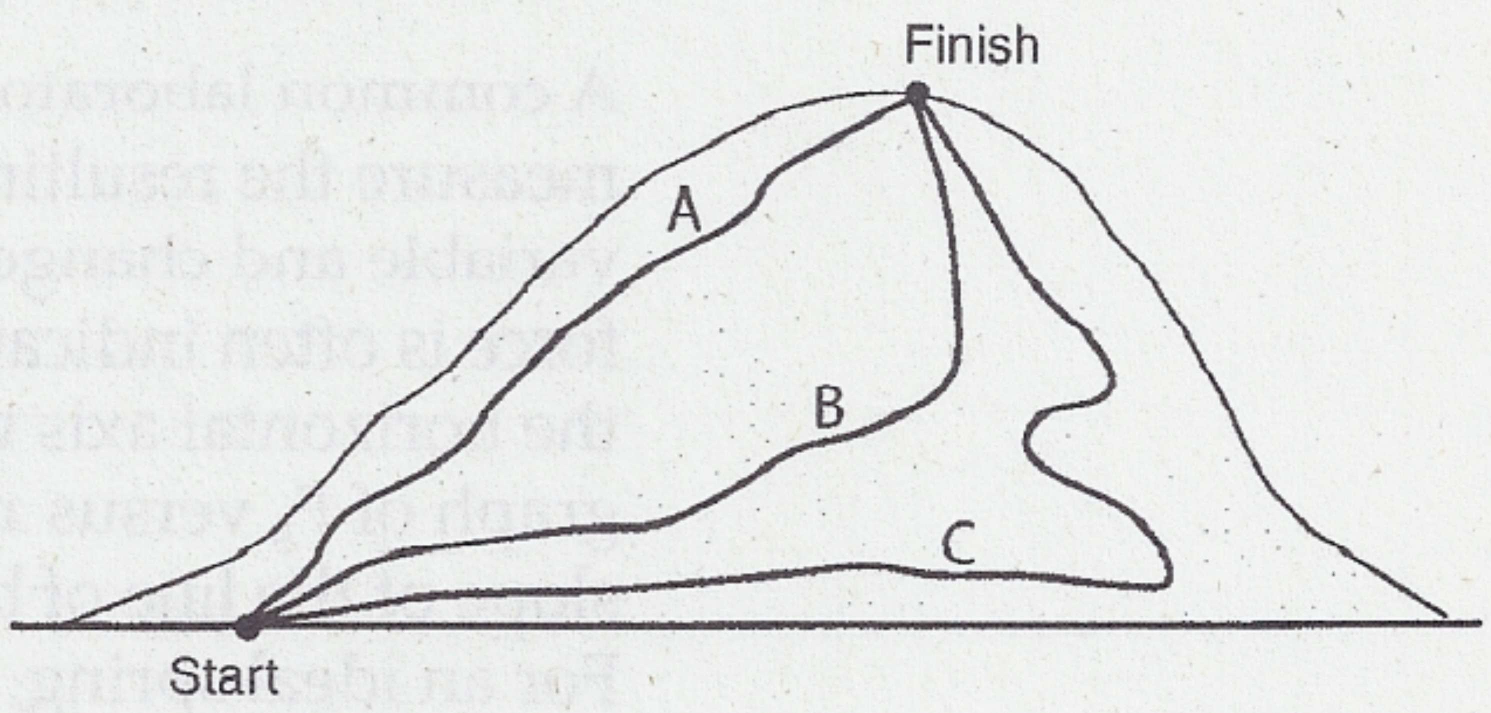
At which point is the gravitational potential energy of the cart least?
(1) A (2) B (3) C (4) D

33. Calculate the gravitational potential energy with respect to Earth's surface gained by a 5.00-kilogram mass as a result of being raised 2.00 meters from Earth's surface.

34. Which graph best represents the relationship between the gravitational potential energy *PE* with respect to the ground and height above the ground *h* for a freely falling object released from rest?



35. Three people of equal mass climb a mountain using paths A, B, and C shown in the diagram below.



Along which path(s) does a person gain the greatest amount of gravitational potential energy from start to finish?
(1) A only
(2) B only
(3) C only
(4) The gain is the same along all paths.

36. A ball is thrown upward from Earth's surface. As the ball rises, what happens to its speed and gravitational potential energy with respect to Earth's surface?
(1) Both speed and gravitational potential energy decrease.
(2) Speed decreases and gravitational potential energy increases.
(3) Speed increases and gravitational potential energy decreases.
(4) Both speed and gravitational potential energy increase.

37. At the top of a frictionless inclined plane, a 0.50-kilogram block of ice possesses 6.0 joules of gravitational potential energy with respect to the bottom of the incline. After sliding halfway down the plane, the block's gravitational potential energy is

(1) 0.0 J (2) 6.0 J (3) 3.0 J (4) 12 J

38. When a 5-kilogram mass is lifted from the ground to a height of 10 meters, the gravitational potential energy of the mass is increased by approximately

(1) 0.5 J (3) 50 J
(2) 2 J (4) 500 J

Elastic Potential Energy

The energy stored in a spring, when work is done in compressing or stretching it, is called **elastic potential energy.** The **compression** or **elongation** of a spring is the change in spring length from its equilibrium position when a force is applied to it. Provided the elastic limit of the spring is not exceeded, the compression or elongation of a spring is directly proportional to the applied force. This relationship, called Hooke's law, is given by the formula:

$$F_s = kx$$ (R)

In the equation, k is the **spring constant,** the constant of proportionality between the applied force F_s and the compression or elongation x of the spring. If F_s is in newtons and x is in meters, then k is in newtons per meter. The SI unit for the spring constant is the newton/meter, N/m.

A common laboratory activity is to vary the force applied to a spring and measure the resulting elongation or compression. Force is the independent variable and change in spring length is the dependent variable. However, force is often indicated on the vertical axis and change in spring length on the horizontal axis when the data from the experiment is graphed. If a graph of F_s versus x is plotted for the data collected for a given spring, the slope of the line of best fit is equal to the spring constant for that spring. For an ideal spring, the line is straight and passes through the origin. A stiff spring has a larger value of k than a weak spring.

If F_s versus x data for two different springs is plotted on the same grid and best-fit lines are drawn, the line for the stiffer spring has the greater slope. On the other hand, if change in spring length from its equilibrium position x is indicated on the vertical axis and the force applied to the spring F_s on the horizontal axis, the slope of the line of best fit is equal to $1/k$, the reciprocal of the spring constant. In this case the line for the stiffer spring has the lesser slope.

Potential Energy of a Spring

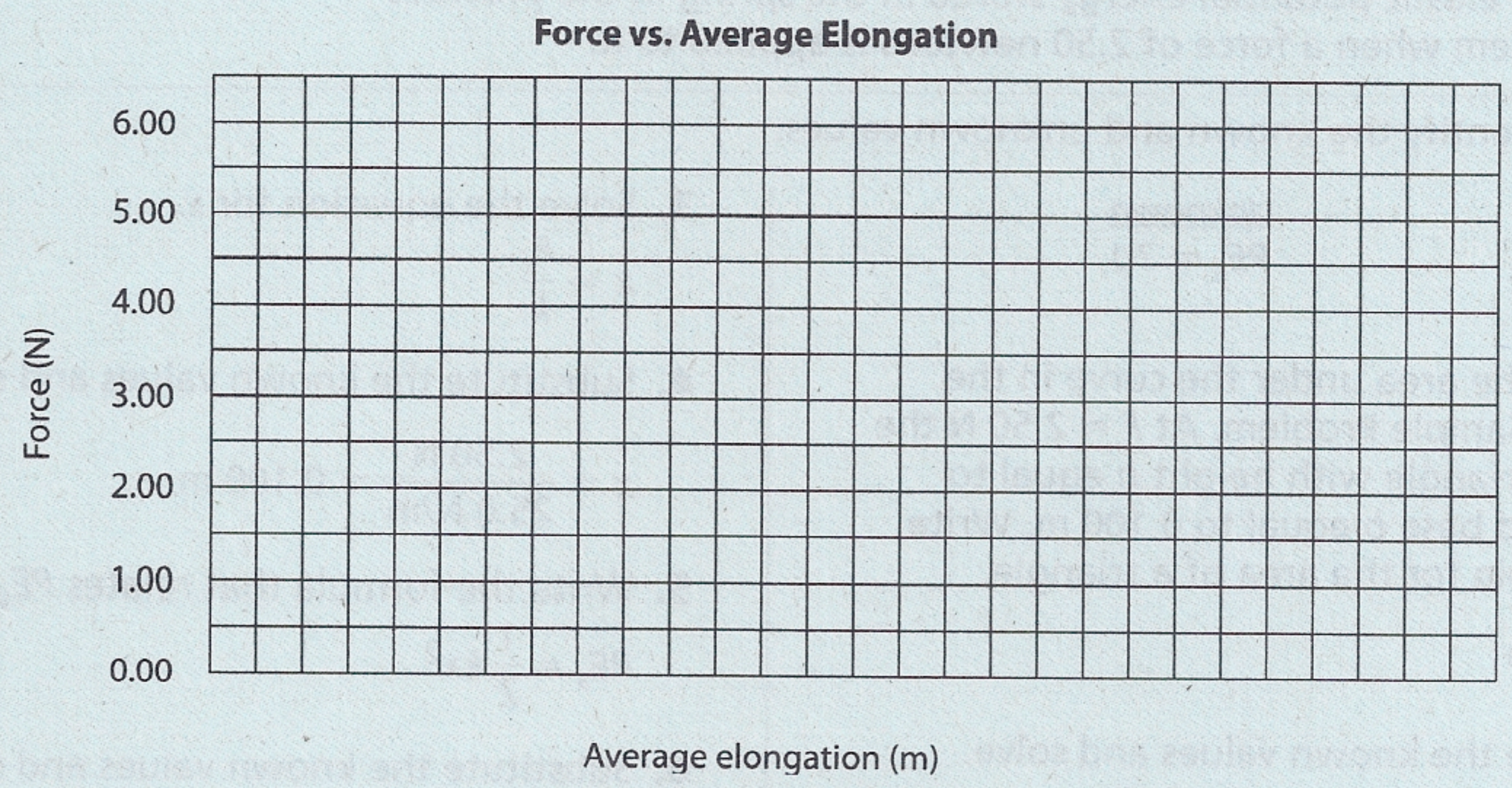
When no force is applied to a spring, there is no change in spring length from the equilibrium position. That is, when $F_s = 0$ N, $x = 0$ m. According to Hooke's law, as F_s increases, x increases. Because F_s increases uniformly from 0 to kx, the *average* applied force equals $\frac{1}{2}kx$. The work done in stretching the spring is equal to the product of the *average* force $\overline{F}_s$ and the elongation x.

SAMPLE PROBLEM

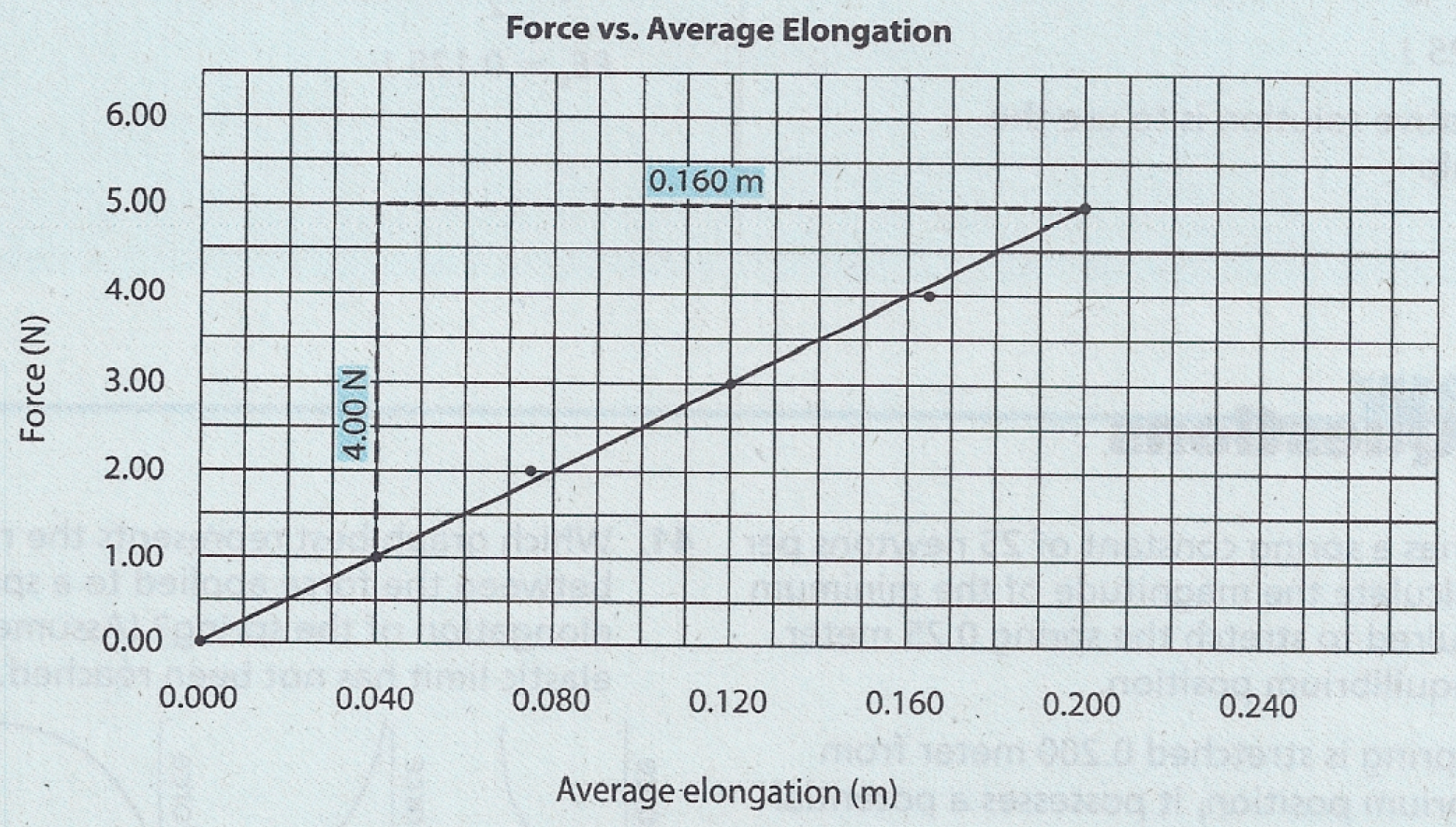
1. In an experiment, a student varied the force applied to a vertically-hung spring and measured the resulting elongation. The table shows the average elongation for three trials with each force.

Force (N)	Average Elongation (m)
0.00	0.000
1.00	0.040
2.00	0.075
3.00	0.120
4.00	0.165
5.00	0.200

2. Using the information in the data table and the grid provided:
(1) Mark an appropriate scale on the axis labeled "Average elongation (m)".
(2) Plot the data points.
(3) Draw the line of best fit.
(4) Use your graph to calculate the spring constant k.



SOLUTION: The spring constant k is the slope of the line.



$$k = \frac{\Delta F}{\Delta x} = \frac{4.00 \text{ N}}{0.160 \text{ m}} = 25.0 \text{ N/m}$$

$$W = \overline{F}_s x = \frac{1}{2}kx \cdot x = \frac{1}{2}kx^2$$

Because the work done on the spring is equal to the spring's elastic potential energy PE_s, the equation can be rewritten in this way:

$$PE_s = \frac{1}{2}kx^2$$

The spring constant k is in newtons per meter, the change in spring length from the equilibrium position x is in meters, and the potential energy stored in the spring PE_s is in newton · meters, or joules. As the following Sample Problem shows, the area under an F_s versus x curve yields a number equal to the number of joules of work done in stretching the spring, and thus, the potential energy stored in the spring.

SAMPLE PROBLEM

Calculate the elastic potential energy stored in the spring in the previous Sample Problem when a force of 2.50 newtons is applied to it.

SOLUTION: Identify the known and unknown values.

Known	*Unknown*
$F_s = 2.50$ N	$PE_s = ?$ J
$k = 25.0$ N/m	

1. Find A_Δ, the area under the curve in the previous Sample Problem. At $F = 2.50$ N the area is a triangle with height h equal to 2.50 N and base b equal to 0.100 m. Write the formula for the area of a triangle.

$$A_\Delta = \frac{1}{2}bh$$

2. Substitute the known values and solve.

$$A_\Delta = PE_s = \frac{1}{2}(0.100 \text{ m})(2.50 \text{ N})$$

$$PE_s = 0.125 \text{ J}$$

An alternative solution is to use the relationship

$$F_s = kx$$

3. Solve the equation for x.

$$x = \frac{F_s}{k}$$

4. Substitute the known values and solve.

$$x = \frac{2.50 \text{ N}}{25.0 \text{ N/m}} = 0.100 \text{ m}$$

5. Write the formula that relates PE_s and x.

$$PE_s = \frac{1}{2}kx^2$$

6. Substitute the known values and solve.

$$PE_s = \frac{1}{2}(25.0 \text{ N})(0.100 \text{ m})^2$$

$$PE_s = 0.125 \text{ J}$$

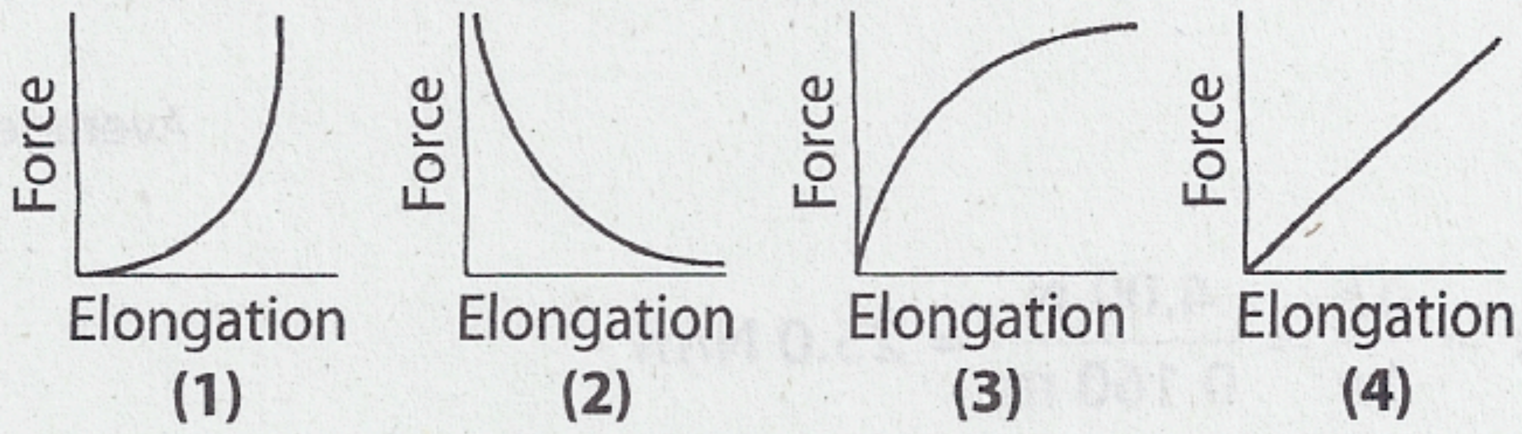
Review Questions

39. A spring has a spring constant of 25 newtons per meter. Calculate the magnitude of the minimum force required to stretch the spring 0.25 meter from its equilibrium position.

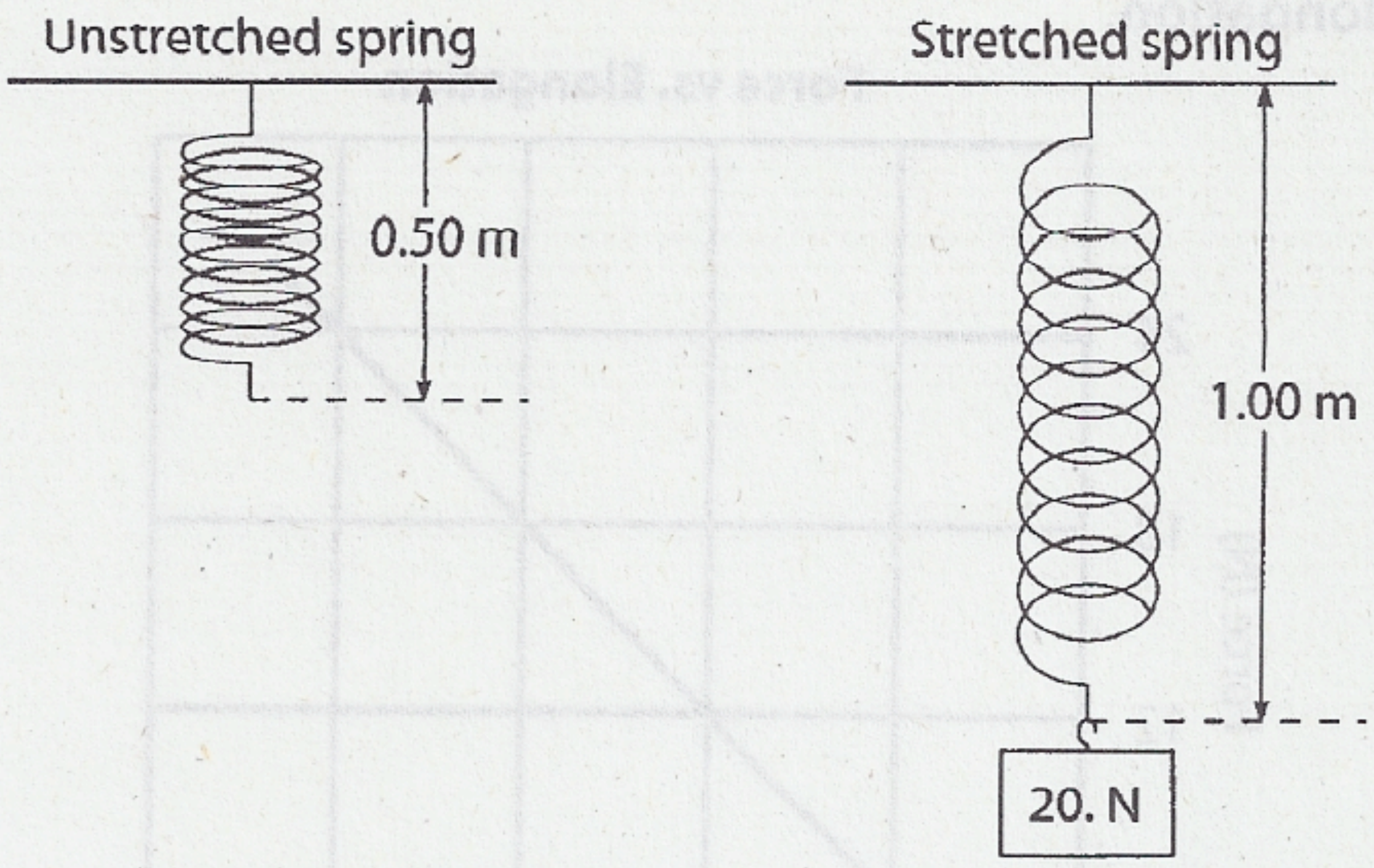
40. When a spring is stretched 0.200 meter from its equilibrium position, it possesses a potential energy of 10.0 joules. What is the spring constant for this spring?

(1) 100. N/m
(2) 125 N/m
(3) 250. N/m
(4) 500. N/m

41. Which graph best represents the relationship between the force applied to a spring and the elongation of the spring? (Assume the spring's elastic limit has not been reached.)



42. A 20.-newton weight is attached to a spring causing it to stretch, as shown in the diagram below.

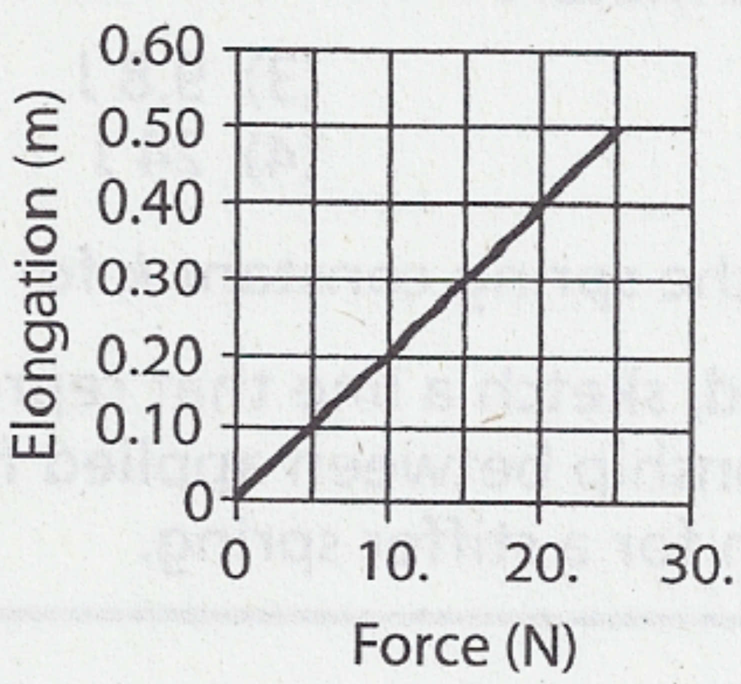


What is the spring constant of this spring?

(1) 0.050 N/m
(2) 0.25 N/m
(3) 20. N/m
(4) 40. N/m

43. The graph below shows the relationship between the elongation of a spring and the force applied to the spring causing it to stretch.

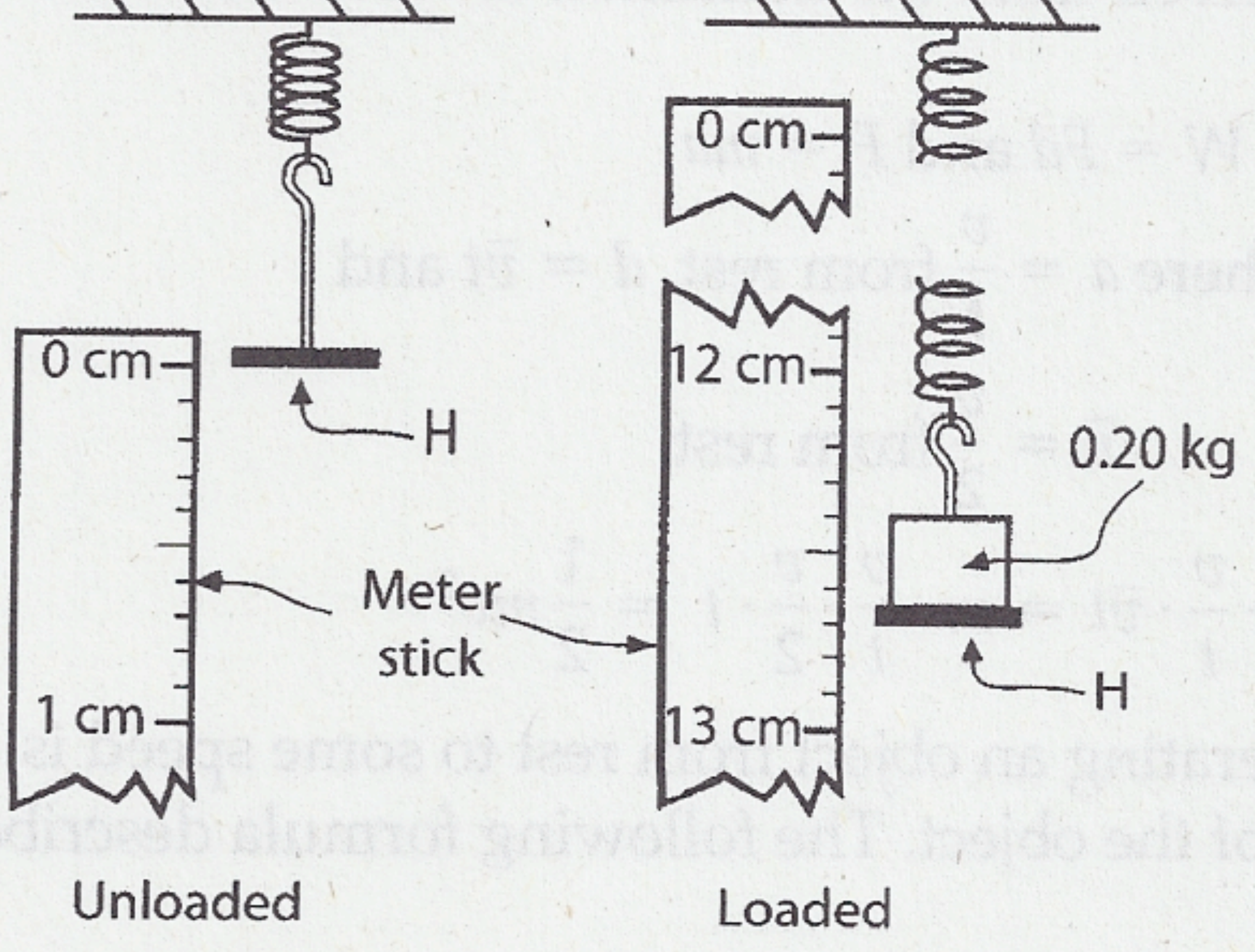
Elongation vs. Applied Force



What is the spring constant for this spring?

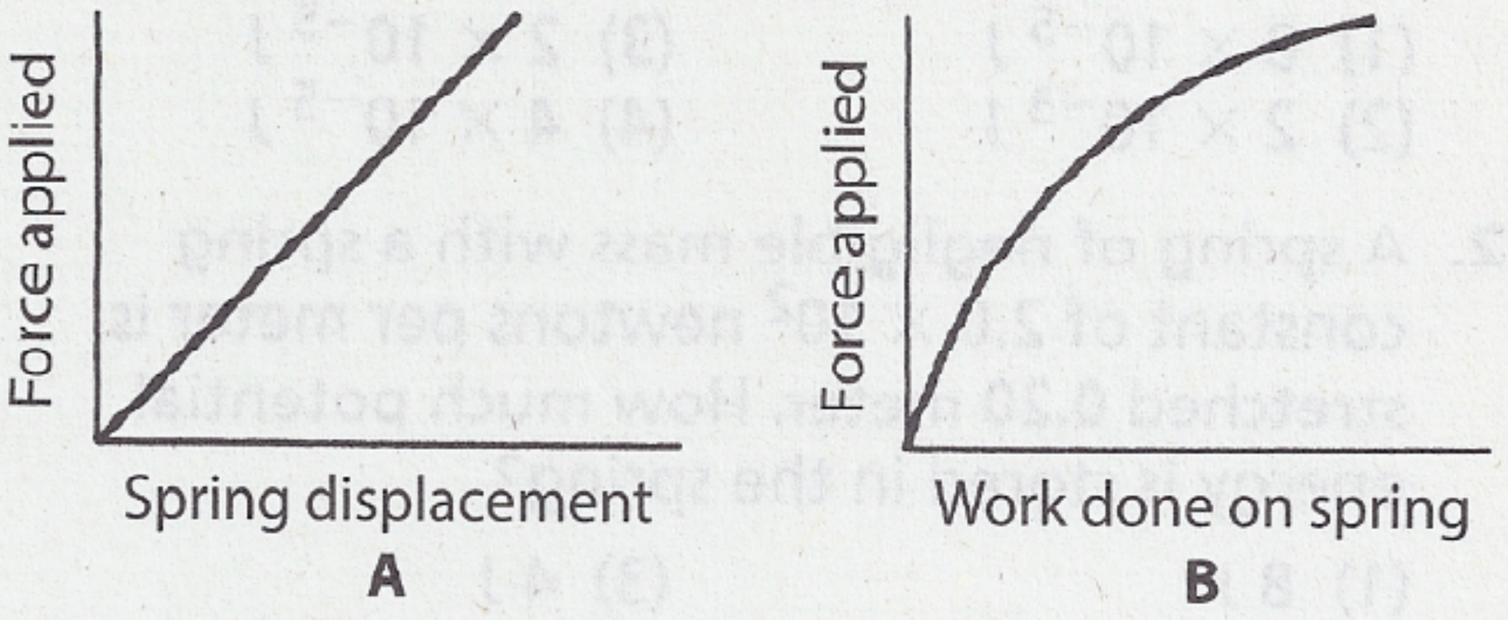
(1) 0.020 N/m
(2) 2.0 N/m
(3) 25 N/m
(4) 50. N/m

44. A mass hanger is attached to a spring, as shown in the diagrams below.



What is the magnitude of the displacement of the mass hanger *H* after a 0.20-kilogram mass is loaded on it? [Assume the hanger is at rest in both positions.]

45. Graphs A and B represent the results of applying an increasing force to stretch a spring. The spring did not exceed its elastic limit.



The spring constant can be represented by the

(1) slope of graph A
(2) slope of graph B
(3) reciprocal of the slope of graph A
(4) reciprocal of the slope of graph B

46. Force F is applied to a spring causing it to stretch a distance x. If force $2F$ is applied to the spring and the elasticity of the spring is not exceeded, the spring will stretch a distance

(1) x
(2) $2x$
(3) $\frac{x}{2}$
(4) $\frac{x}{4}$

47. Which combination of fundamental units can be used to express the elastic potential energy stored in a compressed spring?

(1) $kg \cdot m/s^2$
(2) $kg \cdot m^2/s$
(3) $kg \cdot m^2/s^2$
(4) $kg \cdot m^2/s^3$

48. A force is applied to a spring causing it to stretch. If the applied force is halved, the potential energy stored in the spring will be

(1) halved
(2) doubled
(3) quartered
(4) quadrupled

49. A vertically hung 0.50-meter-long spring is stretched from its equilibrium position to a length of 1.00 meter by a weight attached to the spring. If 15 joules of elastic potential energy are stored in the spring, what is the value of the spring constant?

(1) 30. N/m
(2) 60. N/m
(3) 120 N/m
(4) 240 N/m

50. A spring has a spring constant of 120 newtons per meter. Calculate the elastic potential energy stored in the spring when it is stretched 2.0 centimeters.

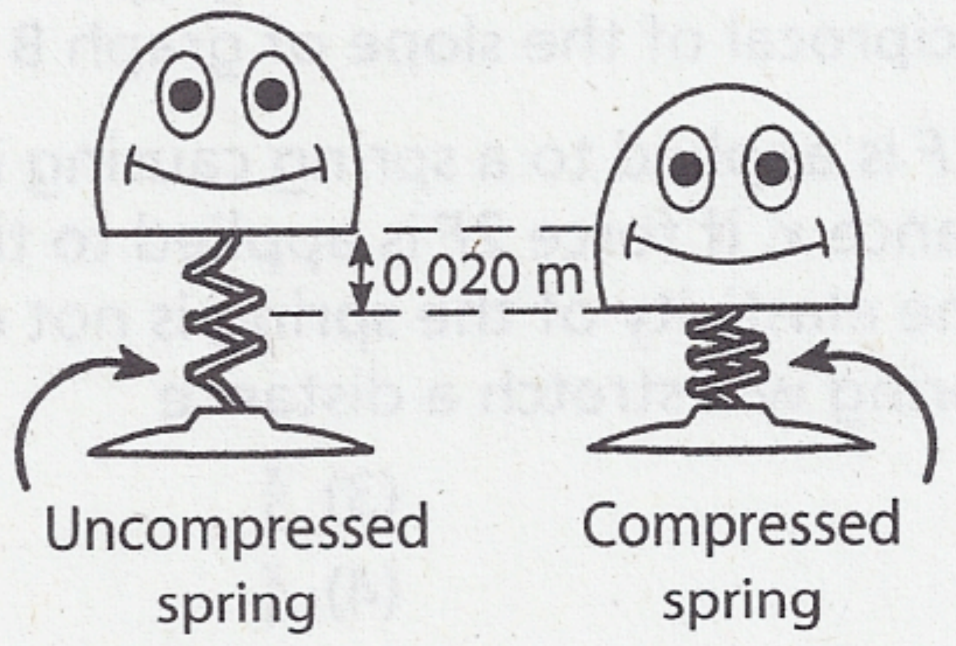
51. A force of 0.2 newton is needed to compress a spring a distance of 0.02 meter. The potential energy stored in this compressed spring is

(1) 8×10^{-5} J
(2) 2×10^{-3} J
(3) 2×10^{-5} J
(4) 4×10^{-5} J

52. A spring of negligible mass with a spring constant of 2.0×10^2 newtons per meter is stretched 0.20 meter. How much potential energy is stored in the spring?

(1) 8 J
(2) 8.0 J
(3) 4 J
(4) 4.0 J

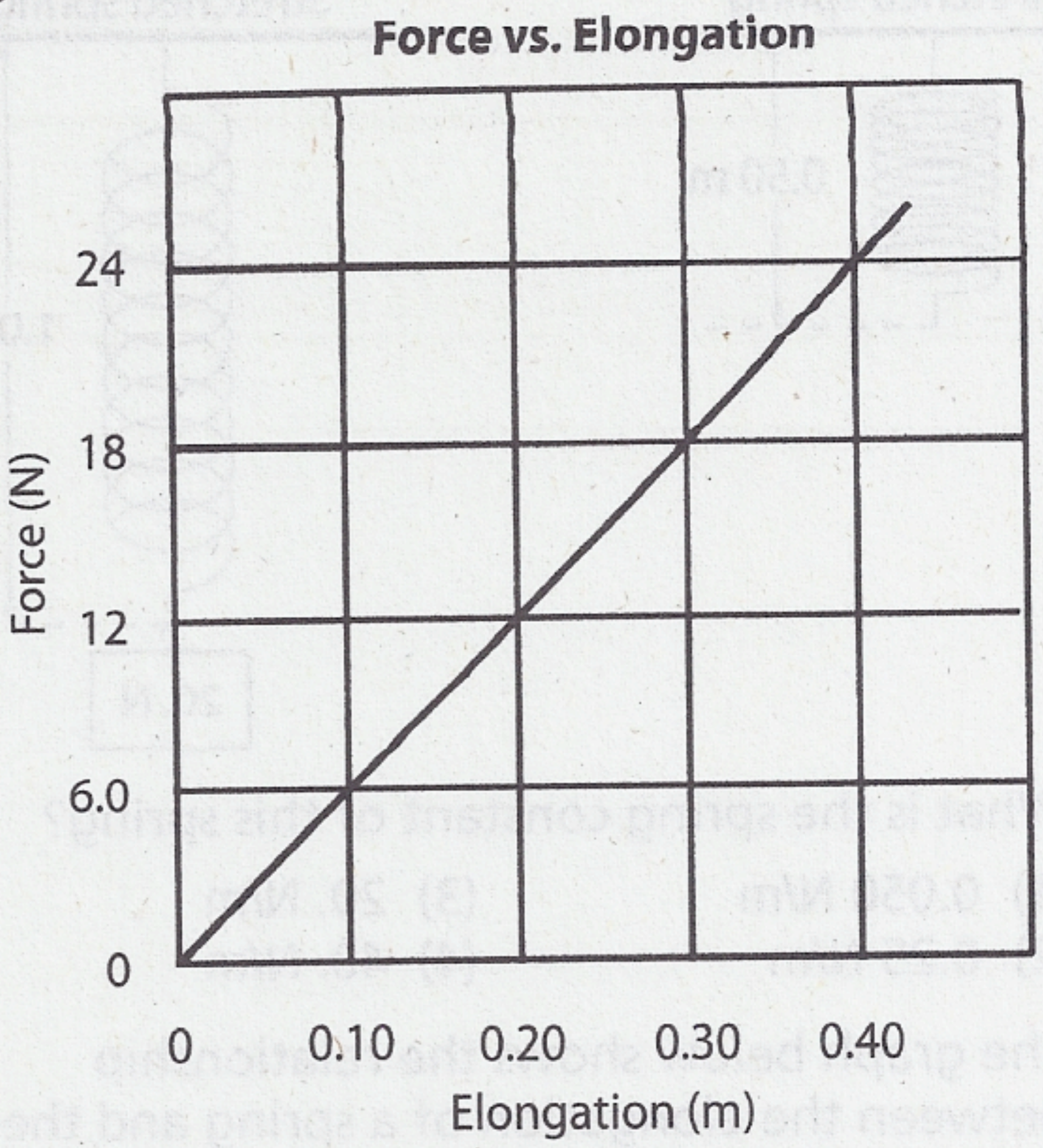
53. In the diagram below, a child compresses the spring in a pop-up toy 0.020 meter.



If the spring has a spring constant of 340 newtons per meter, how much elastic potential energy is being stored in the spring?

(1) 0.068 J
(2) 0.14 J
(3) 3.4 J
(4) 6.8 J

Base your answers to questions 54 through 56 on the graph below, which represents the relationship between the force applied to a spring and its elongation.



54. What is the total work done to stretch the spring 0.40 meter?

(1) 4.8 J
(2) 6.0 J
(3) 9.8 J
(4) 24 J

55. Calculate the spring constant *k* for the spring.

56. On the grid, sketch a line that represents the relationship between applied force and elongation for a stiffer spring.

Kinetic Energy

When a moving object strikes another object and displaces it, the moving object exerts a force on the second object and does work on it. The moving object possesses energy due to its motion. The energy an object possesses due to its motion is called **kinetic energy.** The formula for kinetic energy is $KE = \frac{1}{2}mv^2$ and can be derived from the definition of work and Newton's second law.

$$W = Fd \text{ and } F = ma$$

$$W = mad \text{ where } a = \frac{v}{t} \text{ from rest, } d = \bar{v}t \text{ and}$$

$$\bar{v} = \frac{v}{2} \text{ from rest.}$$

$$W = m \cdot \frac{v}{t} \cdot \bar{v}t = m \cdot \frac{v}{t} \cdot \frac{v}{2} \cdot t = \frac{1}{2}mv^2$$

The net work done in accelerating an object from rest to some speed is equal to the kinetic energy of the object. The following formula describes the relationship:

$$KE = \frac{1}{2}mv^2$$

Ⓡ

Mass m is in kilograms, velocity or speed v is in meters per second, and kinetic energy KE is in kilogram · meter^2/second^2 or joules.

SAMPLE PROBLEM

Calculate the kinetic energy possessed by a 2.7-kilogram cart traveling at 1.5 meter per second.

SOLUTION: Identify the known and unknown values.

Known	*Unknown*
$m = 2.7$ kg	$KE = ?$ J
$v = 1.5$ m/s	

1. Write the formula for kinetic energy.

$$KE = \frac{1}{2}mv^2$$

2. Substitute the known values and solve.

$$KE = \frac{1}{2}(2.7\text{ kg})(1.5\text{ m/s})^2 = 3.0\text{ J}$$

Note: If the weight of the cart had been given, it would have been necessary to use the formula

$g = \frac{F_g}{m}$ to determine the cart's mass.

Review Questions

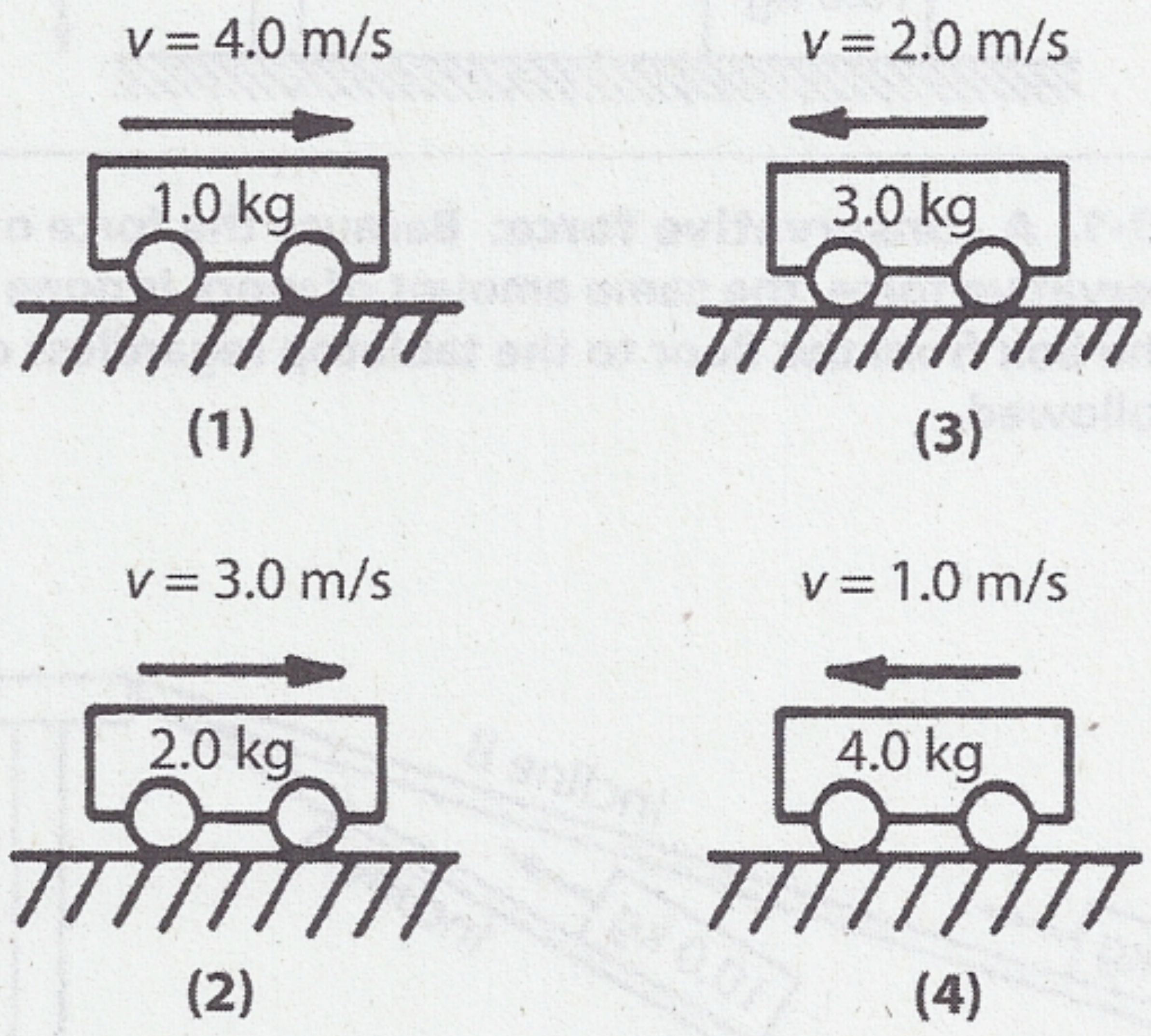
57. If the speed of a car is doubled, its kinetic energy is
(1) halved
(2) doubled
(3) quartered
(4) quadrupled

58. A 1.0×10^3-kilogram car is moving at a constant speed of 4.0 meters per second. What is the kinetic energy of the car?
(1) 1.6×10^3 J
(2) 2.0×10^4 J
(3) 8.0×10^3 J
(4) 4.0×10^3 J

59. A 3.0-kilogram cart possesses 96 joules of kinetic energy. Calculate the speed of the car.

60. A cart of mass m traveling at speed v has kinetic energy KE. If the mass of the cart is doubled and the speed is halved, the kinetic energy of the cart will be
(1) half as great
(2) twice as great
(3) one-fourth as great
(4) four times as great

61. Which cart has the greatest kinetic energy?



62. A 2.0-kilogram cart is initially at rest on a level floor. Determine the kinetic energy of the cart after a constant horizontal 8.0-newton force is applied to the cart over a distance of 1.5 meters.

63. A person does 100 joules of work in pulling back the string of a bow. What is the initial speed of a 0.5-kilogram arrow when it is fired from the bow?

(1) 20 m/s (3) 200 m/s
(2) 50 m/s (4) 400 m/s

64. An 8.0-kilogram object and a 4.0-kilogram object are released simultaneously from a height of 50. meters above the ground. After falling freely for 2.0 seconds, the objects have different

(1) accelerations (3) kinetic energies
(2) speeds (4) displacements

65. The work done in raising an object must result in an increase in the object's

(1) internal energy
(2) kinetic energy
(3) gravitational potential energy
(4) elastic potential energy

66. Two cars having different weights are traveling on a level surface at different constant velocities. Within the same time interval, greater force is always required to stop the car that has the greater

(1) weight (3) velocity
(2) kinetic energy (4) momentum

Work-Energy Relationship

If there is no friction, all the work done in lifting an object to a new height is equal to the object's increase in gravitational potential energy. The change in potential energy depends only on the change in height, not on the path taken. For example, the work done in lifting a 10.0-kilogram box from the floor to a 0.92-meter high tabletop is equal to the box's change in gravitational potential energy.

$$W = \Delta PE = mg\Delta h = (10.0\text{ kg})(9.81\text{ m/s}^2)(0.92\text{ m}) = 90.\text{ J}$$

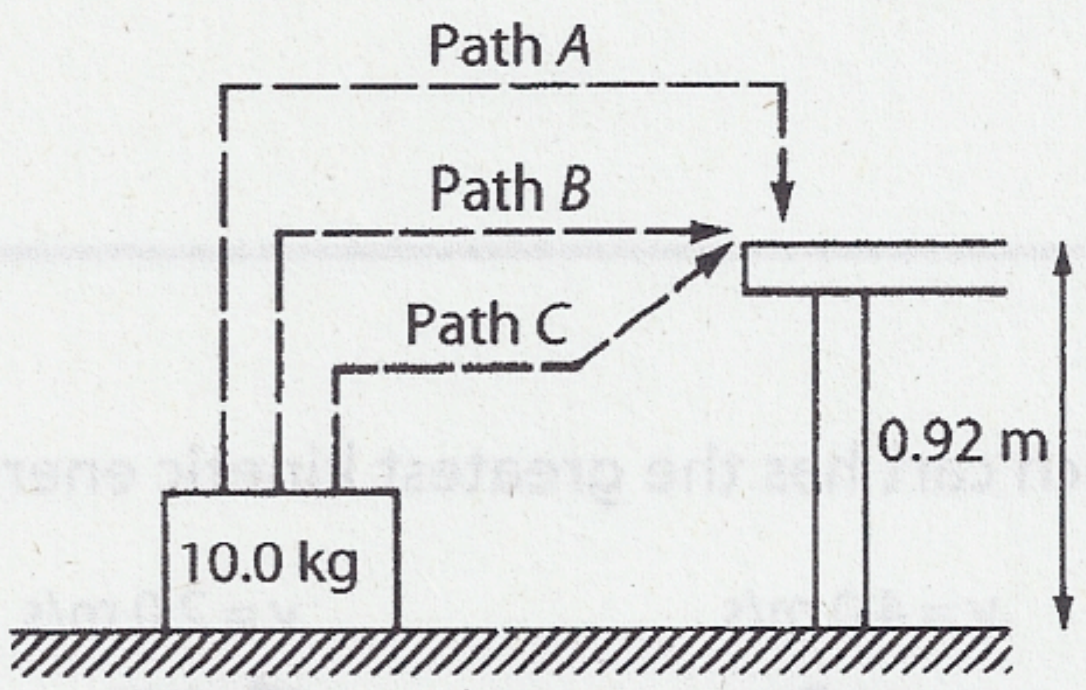


Figure 3-1. A conservative force: Because the force of gravity is a conservative force, the same amount of work is done when raising the box from the floor to the tabletop regardless of which path is followed.

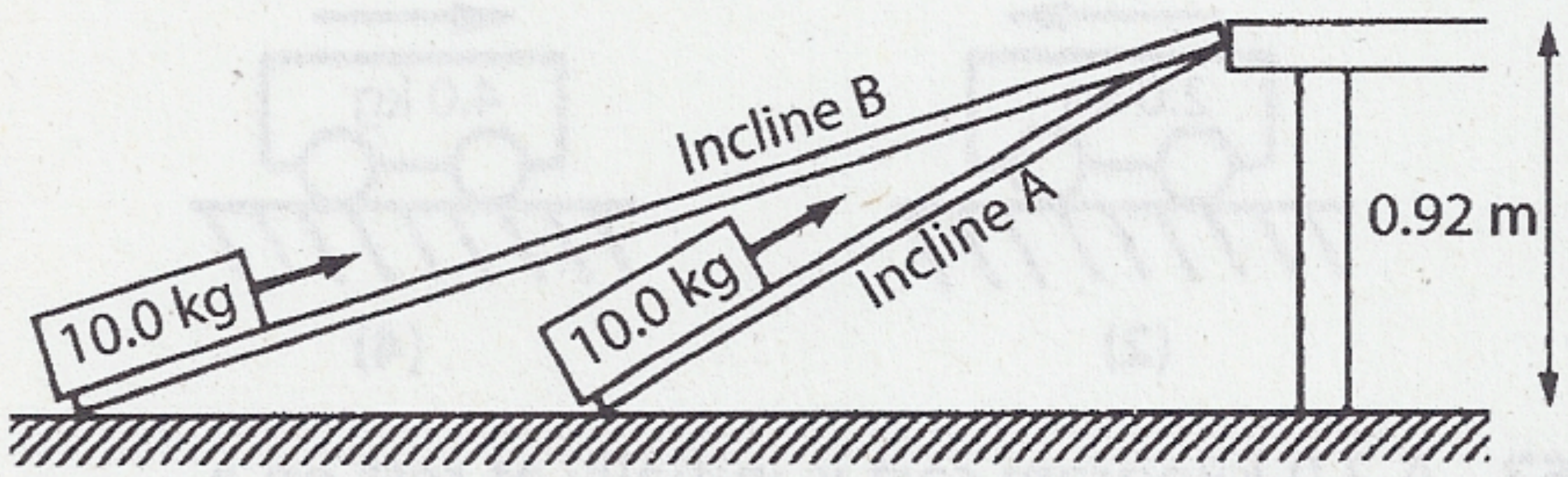


Figure 3-2. A nonconservative force: Because friction is a nonconservative force, moving the box from the floor to the tabletop requires more work on incline B than on incline A. In this case, the path makes a difference in the amount of work required. (Read the explanation in the text.)

Figure 3-1 shows that the work done in moving the box from the floor to the tabletop is the same regardless of the path taken. When work done against a force is independent of the path taken, the force is said to be a conservative force. The force of gravity is an example of a conservative force. The elastic force of a spring is also a conservative force. Potential energy has meaning only in relation to work done against conservative forces.

Air resistance and friction are examples of nonconservative forces. The work done against a nonconservative force is dependent upon the path taken. In Figure 3-2, the same box is moved from the floor to the tabletop by sliding it along an inclined plane A. Once again, 90. joules of work is done to change the gravitational potential energy of the box, but because additional work must be done against friction, the total work done is greater than 90. joules.

If inclined plane B is used instead of inclined plane A, the work done against friction, $W_f = F_f d$, is greater, even though the coefficient of friction is the same for both planes. The force of friction F_f is greater when a plane is inclined at a smaller angle because the normal force F_N for the same object, on the incline is larger and $F_f = \mu F_N$. In addition, the frictional force acts over a greater distance on incline B. Because friction is a nonconservative force, the work required to raise the box from the floor to the top of the table on incline B is greater than the work required to raise it on incline A.

Conservation of Energy

A closed system is one in which there are no external forces doing work on the system, no external work being done by the system, and no transfer of energy into or out of the system. In a closed system, the sum of the potential energy (gravitational and/or elastic), kinetic energy, and internal energy remains constant. Although the energy within a closed system may be transformed from one type to another, the total energy of the system always remains the same. These ideas are expressed in the **law of conservation of energy,** which states that energy cannot be created or destroyed. In other words, the sum of the *changes* in energy (potential, kinetic, and internal) within a closed system is zero.

Ideal Mechanical Systems

The sum of the kinetic and potential energies in a system is called the total **mechanical energy.** An **ideal mechanical system** is a closed system in which no friction or other nonconservative force acts. In an ideal mechanical system, the sum of the kinetic and potential energies is constant, or the sum of the *changes* in kinetic and potential energy is zero.

The relationship between the gravitational potential energy and kinetic energy for an ideal simple pendulum is shown in Figure 3-3. A **simple pendulum** consists of a mass (bob) attached to one end of a string or wire that is attached at the other end to a pivot point.

An object falling freely from rest in a vacuum is another example of an ideal mechanical system. If a stationary object having mass m is located a vertical distance h above Earth's surface, the object has initial gravitational potential energy, $PE_i = mgh$ with respect to Earth and kinetic energy, $KE_i = 0$. As the object falls, its gravitational potential energy decreases, but because its speed increases, the object's kinetic

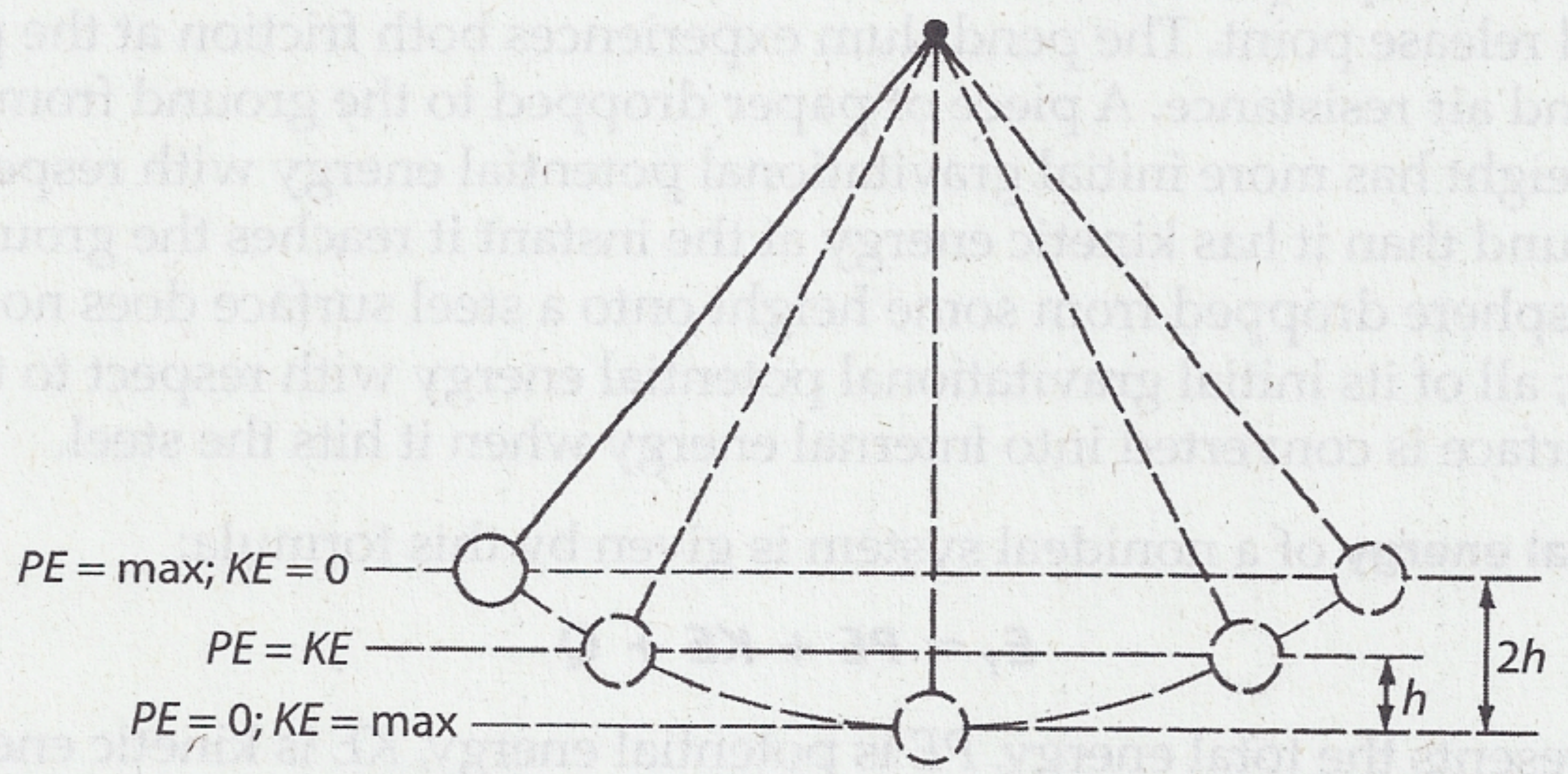


Figure 3-3. The relationship between gravitational potential energy with respect to the lowest point and kinetic energy for an ideal simple pendulum

energy increases. These energy changes can be expressed by the law of conservation of energy:

$$\Delta PE + \Delta KE = 0$$

or

$$\Delta KE = -\Delta PE$$

As the object falls from rest, its change in gravitational potential energy is given by $\Delta PE = -mgh$, and its change in kinetic energy is $\Delta KE = \frac{1}{2}mv^2$. These expressions can be substituted into the previous equations:

$$\frac{1}{2}mv^2 - mgh = 0$$

or

$$\frac{1}{2}mv^2 = mgh$$

The common factor, m, can be eliminated:

$$\frac{1}{2}v^2 = gh, \text{ so } v^2 = 2gh \text{ and } v = \sqrt{2gh}$$

The acceleration due to gravity, g, can be considered constant near Earth's surface, so the last equation can be used to determine the speed of an object falling from rest from a known height. Note that the speed of the object is independent of its mass.

Nonideal Mechanical Systems

When a system is acted upon by a nonconservative force, such as friction, it is called a **nonideal mechanical system.** In reality, friction opposes the motion of two objects in contact with each other and moving relative to each other. Frictional force converts some or all of the kinetic energy of a moving object into internal energy, that is, potential or kinetic energy of the individual particles that comprise the object. The "lost" kinetic energy usually appears as an increase in temperature of the objects in contact. For example, a simple pendulum set in motion in air does not swing back to its original release point. The pendulum experiences both friction at the pivot point and air resistance. A piece of paper dropped to the ground from some height has more initial gravitational potential energy with respect to the ground than it has kinetic energy at the instant it reaches the ground. A lead sphere dropped from some height onto a steel surface does not bounce; all of its initial gravitational potential energy with respect to the steel surface is converted into internal energy when it hits the steel.

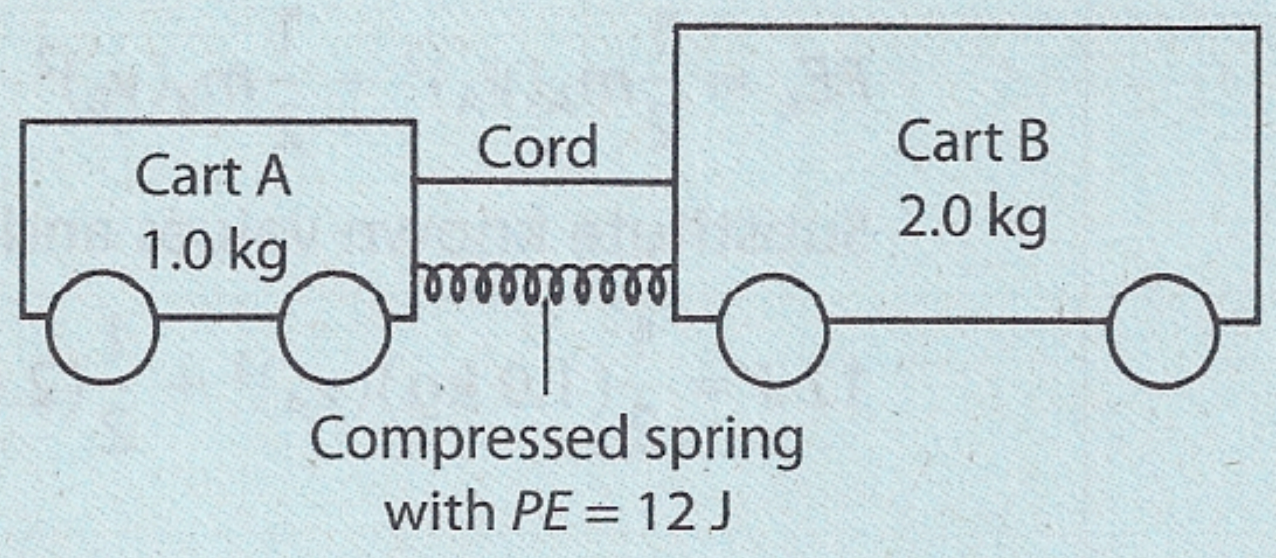
The **total energy** of a nonideal system is given by this formula:

$$E_T = PE + KE + Q$$ (R)

E_T represents the total energy, PE is potential energy, KE is kinetic energy, and Q is internal energy. All quantities are expressed in joules.

SAMPLE PROBLEM

A 1.0-kilogram cart A and a 2.0-kilogram cart B are at rest on a frictionless table, as shown in the diagram. A cord and a spring of negligible mass join the two carts. The spring is compressed 0.060 meter between the two carts until the elastic's potential energy stored in the spring is 12 joules. When the cord is cut, the spring will force the carts apart.



(1) Determine the total amount of work done in compressing the spring.
(2) Calculate the spring constant for the spring.
(3) Calculate the magnitude of the average force required to compress the spring 0.060 meter.
(4) Compare the following quantities while the spring is pushing the carts apart:
  (a) the forces acting on the two carts
  (b) the change in momentum of the two carts
  (c) the total initial and final momentum of the two carts
  (d) the acceleration of the two carts
(5) Calculate the final velocity of cart A.
(6) Determine the ratio of the maximum kinetic energy of cart A to the maximum kinetic energy of cart B.

SOLUTION: Identify the known and unknown values.

Known	Unknown
$m_A = 1.0$ kg	$W = ?$ J
$m_B = 2.0$ kg	$k = ?$ N/m
$x = 0.060$ m	$F_s = ?$ N
$PE_s = 12$ J	$v_{f_A} = ?$ m/s

1. The work done in compressing the spring is equal to the potential energy stored in the spring.

$W = PE_s = 12$ J

2. Write the formula for the potential energy of a spring.

$$PE_s = \frac{1}{2}kx^2$$

Solve the equation for k.

$$k = \frac{2PE_s}{x^2}$$

Substitute the known values and solve.

$$k = \frac{2(12\text{ J})}{(0.060\text{ m})^2}$$

$$k = 6.7 \times 10^3 \text{ N/m}$$

3. Write the formula for the average force needed to compress the spring.

$F_s = kx$

Substitute the known values and solve.

$F_s = (6.7 \times 10^3 \text{ N/m})(0.060 \text{ m})$

$F_s = 4.0 \times 10^2$ N

4. The forces are equal in magnitude and opposite in direction.

Momentum must be conserved. Thus, the change in momentum is equal in magnitude and opposite in direction for the two carts at all times.

The total momentum is zero at all times, because the carts were initially at rest.

The forces on the two carts are equal in magnitude and the mass of A is one half the mass of B. Thus, the acceleration of cart A is twice that of cart B and opposite in direction.

5. Write an equation for the relationship between the initial and final momentum of the system. Because momentum must be conserved, the initial momentum of the system, which is zero, must equal the final momentum.

$p_{before} = p_{after} = 0$

Write this equality in terms of mass and velocity.

$m_A v_A + m_B v_B = 0$

Solve the equation for v_B.

$m_B v_B = -m_A v_A$

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

Substitute known values and solve.

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

$$v_B = -\frac{1}{2}v_A$$

Recognizing that energy is conserved, write an equation that equates the total initial energy of the system and the total final energy of the system.

$PE_i + KE_i + PE_{s_i} = PE_f + KE_f + PE_{s_f}$

$PE_i = PE_f$, $PE_{s_f} = 0$, and $KE_i = 0$

Thus, because energy is conserved, the final kinetic energy of the two carts equals the initial potential energy of the spring.

$PE_{s_i} = KE_f$

Write an equation in terms of mass and velocity that states this relationship.

$$PE_{s_i} = \frac{1}{2}m_A(v_A)^2 + \frac{1}{2}m_B(v_B)^2$$

Substitute known values and solve for v_A.

$$12\text{ J} = \frac{1}{2}(1.0\text{ kg})(v_A)^2 + \frac{1}{2}(2.0\text{ kg})\left(-\frac{v_A}{2}\right)^2$$

$$12\text{ J} = (0.50\text{ kg})(v_A)^2 + (1.0\text{ kg})\left(\frac{v_A^2}{4}\right)$$

$$12\text{ J} = (0.75\text{ kg})v_A^2$$

$$v_A^2 = 16\text{ J/kg} = 16\,\frac{\text{kg}\cdot\text{m}^2/\text{s}^2}{\text{kg}}$$

$v_A = 4.0\text{ m/s}$

6. It has already been determined that the speed of cart B is one-half that of cart A, thus

$$\frac{KE_A}{KE_B} = \frac{\frac{1}{2}m_A v_A^2}{\frac{1}{2}m_B v_B^2} = \frac{\frac{1}{2}(1.0\text{ kg})(4.0\text{ m/s})^2}{\frac{1}{2}(2.0\text{ kg})(2.0\text{ m/s})^2} = \frac{2}{1}$$

Review Questions

67. As the speed of an object falling toward Earth increases, the gravitational potential energy of the object with respect to Earth

(1) decreases (3) remains the same
(2) increases

68. At what point in its fall does the kinetic energy of a freely falling object equal its gravitational potential energy with respect to the ground?

(1) at the start of the fall
(2) halfway between the start and the end
(3) at the end of the fall
(4) at all points during the fall

69. A 2.0-kilogram mass falls freely for 10. meters near the surface of Earth. The total kinetic energy gained by the object during its free fall is approximately

(1) 400 J (2) 200 J (3) 100 J (4) 50 J

70. A 20.0-kilogram object falls freely from rest and strikes the ground with 1,962 joules of kinetic energy. Calculate how far above the ground the object was when it was released.

71. A 1.0-kilogram mass gains kinetic energy as it falls freely from rest a vertical distance *d*. How far would a 2.0-kilogram mass have to fall freely from rest to gain the same amount of kinetic energy?

(1) d (2) $2d$ (3) $\frac{d}{2}$ (4) $\frac{d}{4}$

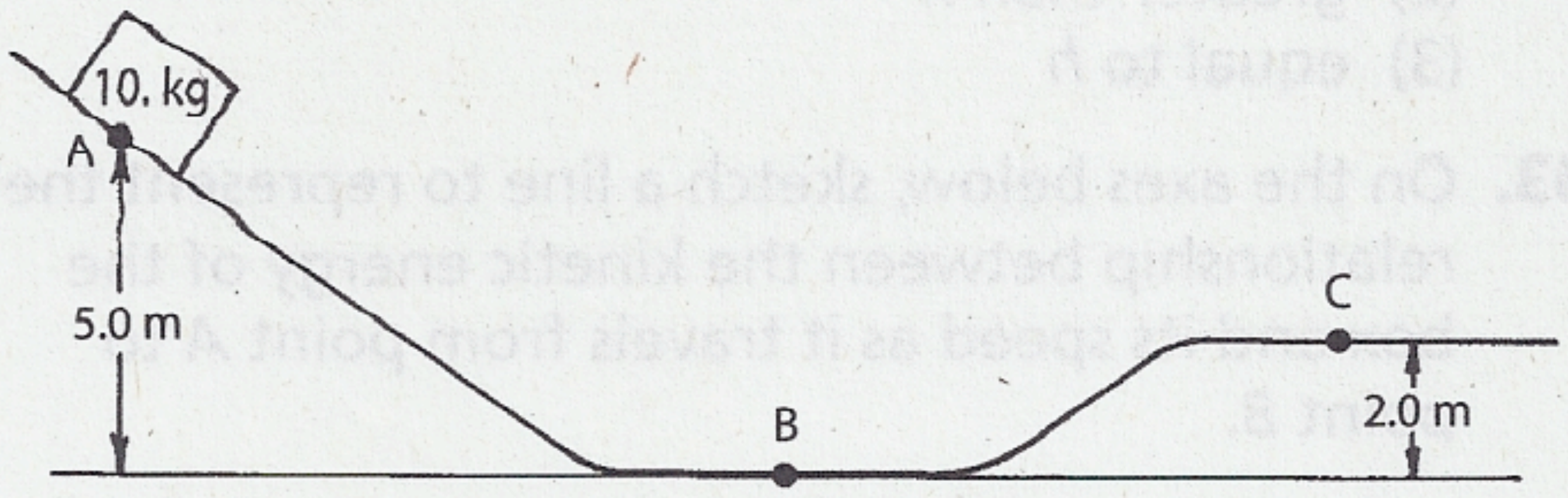
72. A basketball player, who weighs 600 newtons, jumps 0.5 meter vertically off the floor. Calculate her kinetic energy just before hitting the floor.

73. As an object falls freely in a vacuum, the total mechanical energy of the object

(1) decreases (3) remains the same
(2) increases

Base your answers to questions 74 through 76 on the information and diagram below.

A 10-kilogram block starts from rest at point A and slides along a frictionless track. [Neglect air resistance.]



74. As the block moves from point A to point B, the total amount of gravitational potential energy that changes to kinetic energy is approximately

(1) 5 J (2) 20 J (3) 50 J (4) 500 J

75. What is the approximate speed of the block at point B?

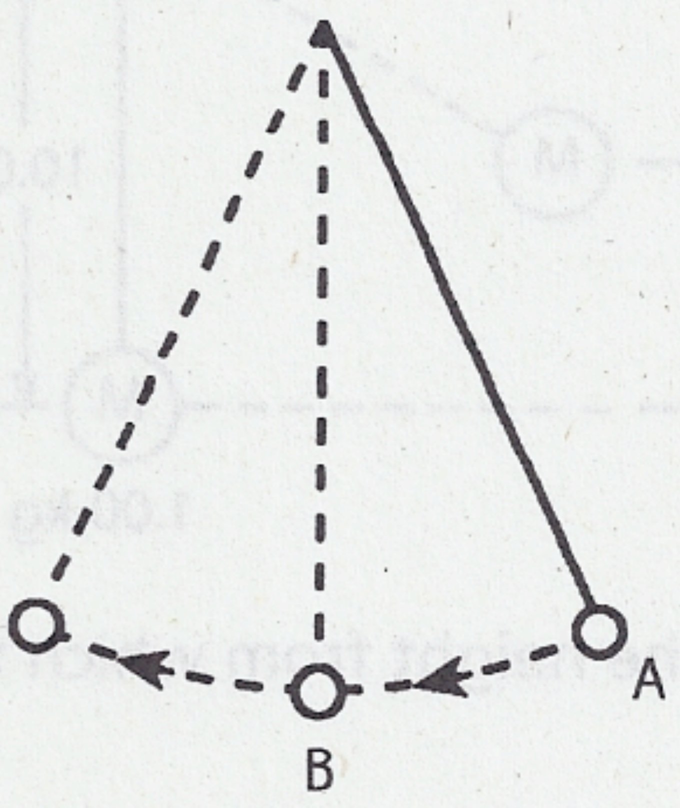
(1) 1 m/s (2) 10 m/s (3) 50 m/s (4) 100 m/s

76. What is the approximate gravitational potential energy of the block at point C?

(1) 20 J (2) 200 J (3) 300 J (4) 500 J

Base your answers to questions 77 and 78 on the information and diagram below.

An ideal simple pendulum is released from rest at position *A* and swings freely through position *B*. [Assume that the gravitational potential energy of the system is zero at *B*.]



77. Compared to the pendulum's kinetic energy at position *B*, its gravitational potential energy at position *A* is

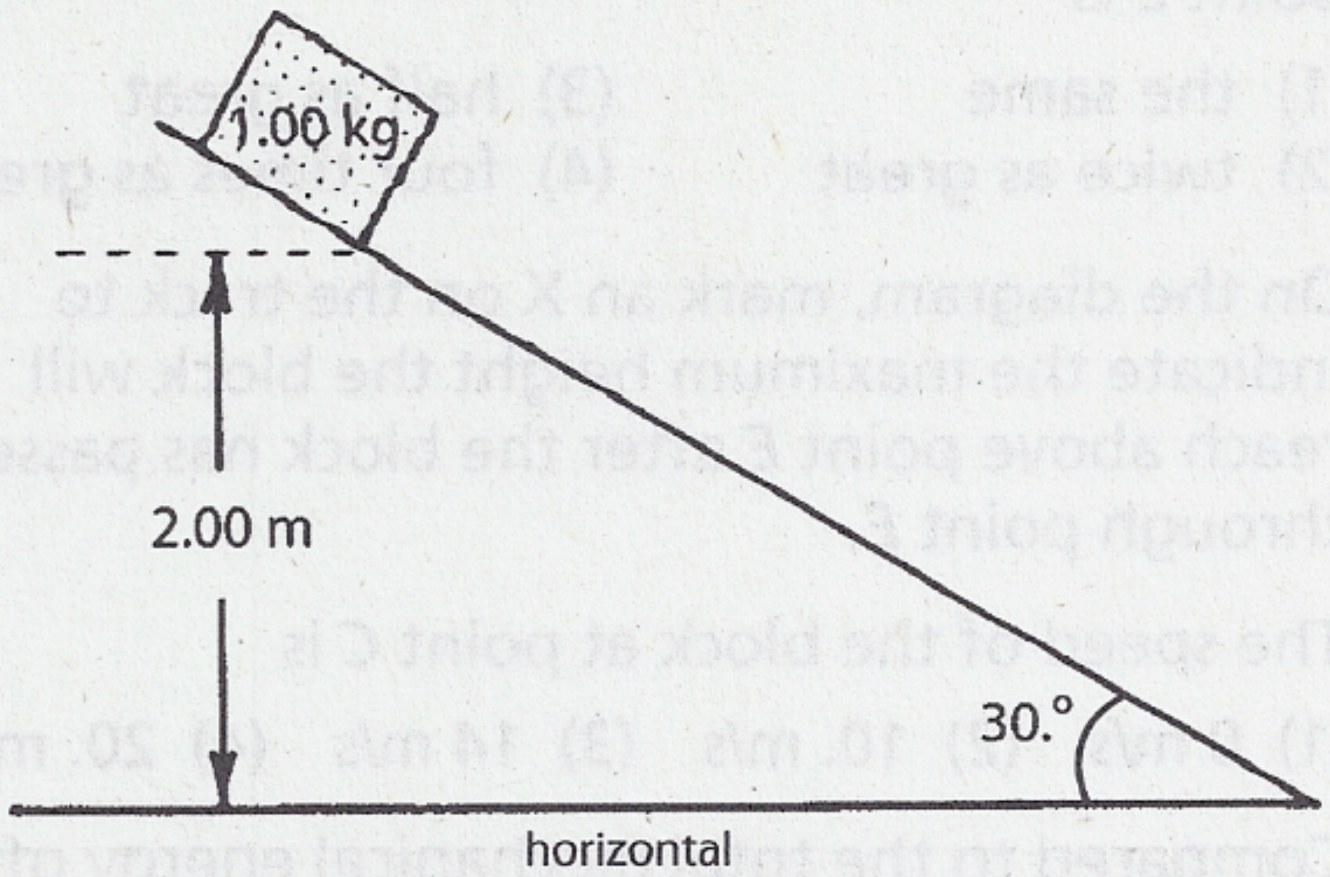
(1) half as great
(2) twice as great
(3) the same
(4) four times as great

78. As the pendulum swings from position *A* to position *B*, the total mechanical energy of the pendulum

(1) decreases
(2) increases
(3) remains the same

Base your answers to questions 79 through 81 on the information and diagram below.

A 1.00-kilogram block is held at rest on a frictionless plane inclined at 30.° to the horizontal.



79. The block is released and slides down the length of the incline. Determine the block's kinetic energy at the bottom of the incline.

80. If the angle between the plane and the horizontal is increased, the magnitude of the force required to hold the block at rest on the incline will

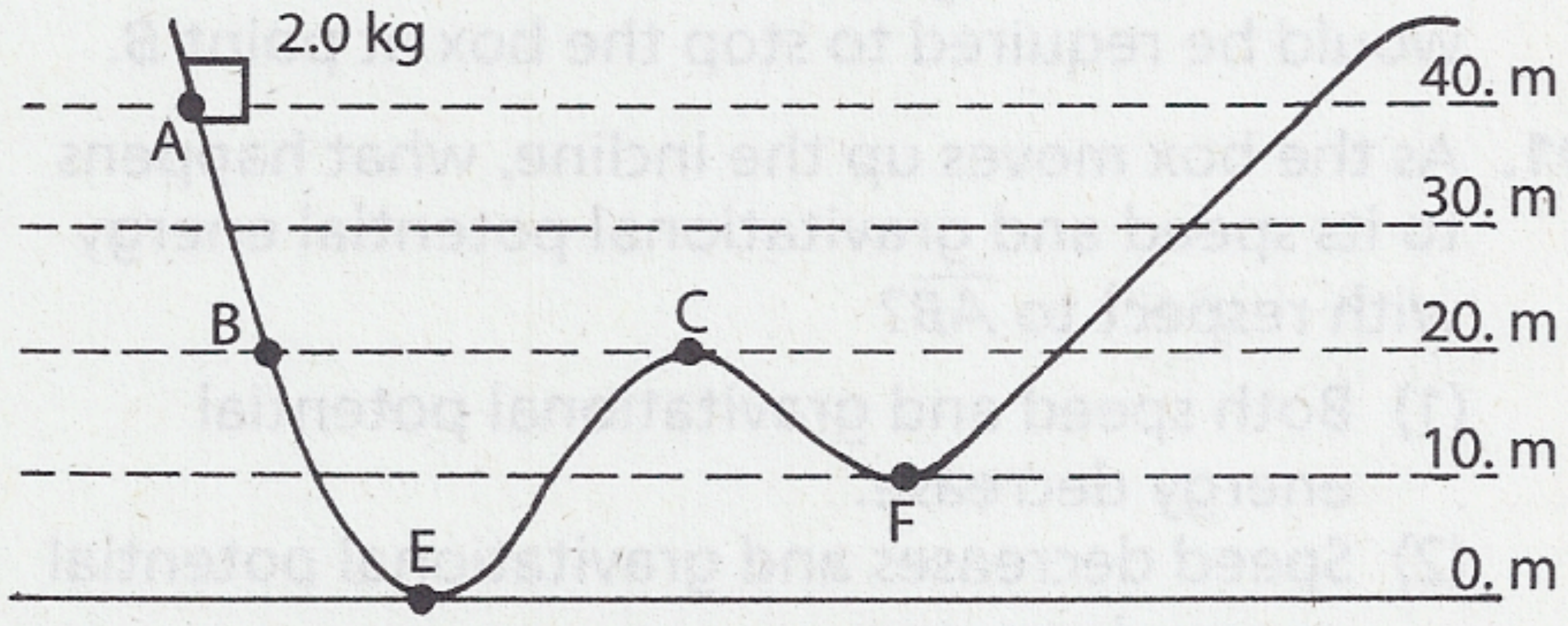
(1) decrease
(2) increase
(3) remain the same

81. As the block slides down the incline, the sum of its gravitational potential energy with respect to the horizontal and kinetic energy

(1) decreases
(2) increases
(3) remains the same

Base your answers to questions 82 through 86 on the information and diagram below.

A 2.0-kilogram block is placed on a frictionless track at point A and released from rest. [Assume that the gravitational potential energy of the system is zero at point E.]



82. Calculate the gravitational potential energy of the system at point A.

83. Compared to the kinetic energy of the block at point *B*, the kinetic energy of the block at point *E* is

(1) the same
(2) twice as great
(3) half as great
(4) four times as great

84. On the diagram, mark an X on the track to indicate the maximum height the block will reach above point *E* after the block has passed through point *E*.

85. The speed of the block at point C is

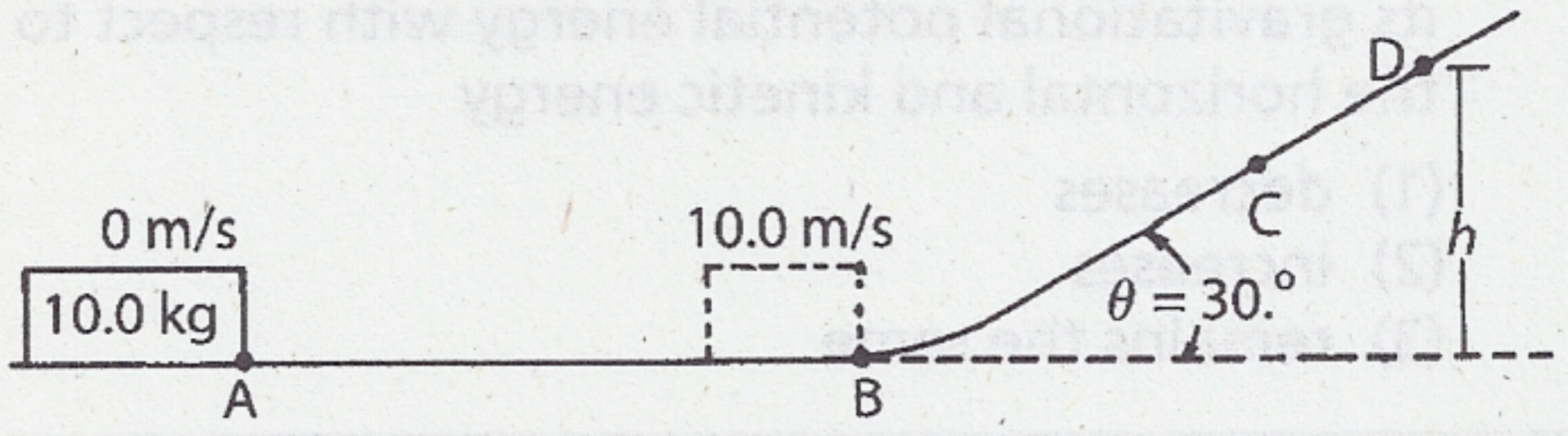
(1) 0 m/s (2) 10. m/s (3) 14 m/s (4) 20. m/s

86. Compared to the total mechanical energy of the system at point *A*, the total mechanical energy of the system at point *F* is

(1) less (2) more (3) the same

Base your answers to questions 87 through 93 on the information and diagram below.

A 10.0-kilogram box starts from rest at point A and is accelerated uniformly to point B in 4.0 seconds by the application of a constant horizontal force *F*. At point *B*, the speed of the box is 10.0 meters per second as it begins to move up a plane inclined at 30.° to the horizontal. [Neglect friction.]



87. Calculate the kinetic energy of the box at point *B*.

88. Calculate the magnitude of force *F*.

89. Calculate the distance the box travels in moving from point *A* to point *B*.

90. Calculate the magnitude of the impulse that would be required to stop the box at point *B*.

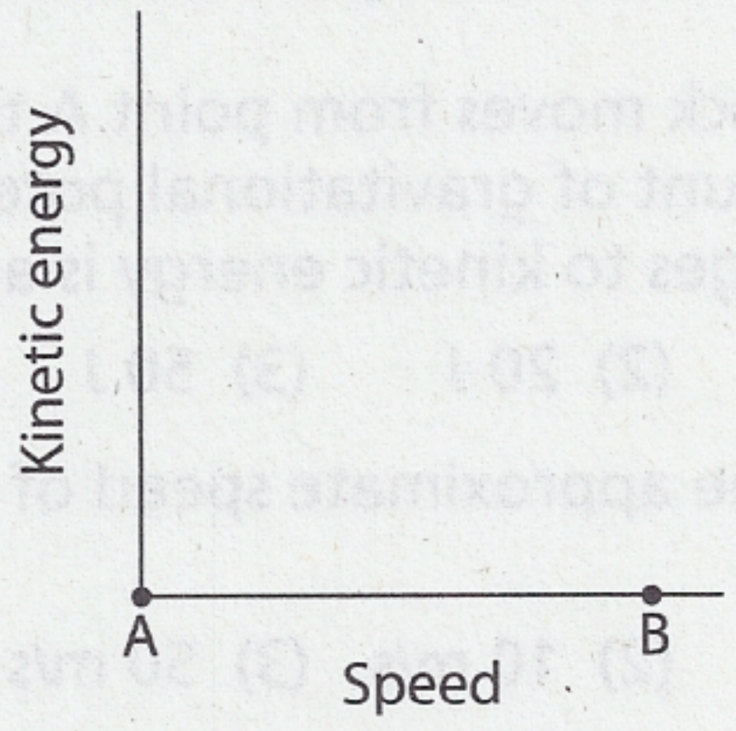
91. As the box moves up the incline, what happens to its speed and gravitational potential energy with respect to $\overline{AB}$?

(1) Both speed and gravitational potential energy decrease.
(2) Speed decreases and gravitational potential energy increases.
(3) Speed remains the same and gravitational potential energy decreases.
(4) Speed remains the same and gravitational potential energy increases.

92. The box comes to rest at a vertical height of *h* (point D) when *∠θ = 30.°. If ∠θ was increased* to 40.°, the box would come to rest at a vertical height

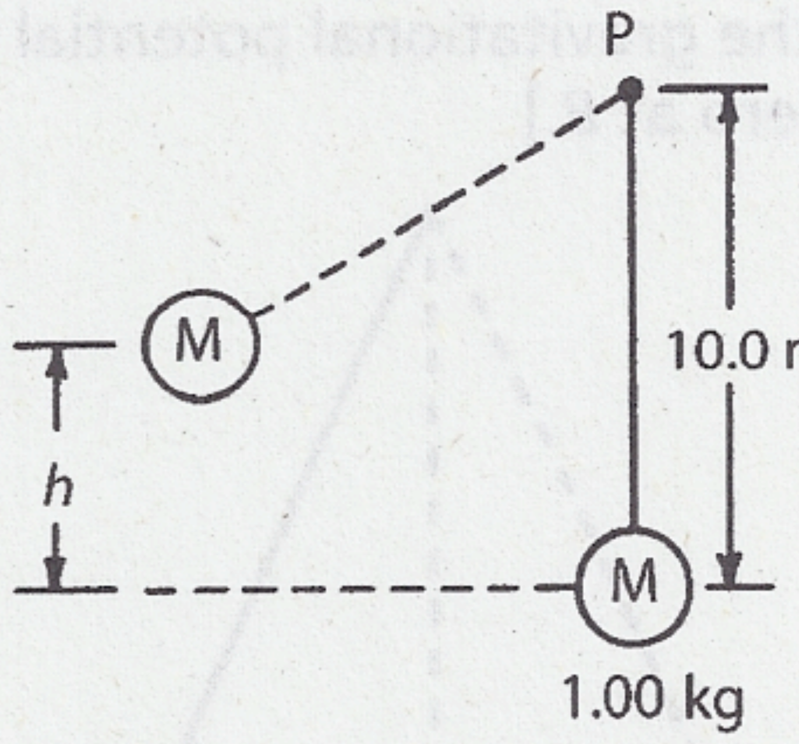
(1) less than *h*
(2) greater than *h*
(3) equal to *h*

93. On the axes below, sketch a line to represent the relationship between the kinetic energy of the box and its speed as it travels from point *A* to point *B*.



Base your answers to questions 94 through 97 on the information and diagram below.

A 1.00-kilogram sphere M, suspended by a string from point P, is lifted to a height *h*. The sphere is released and passes through the lowest point in its swing at a speed of 10.0 meters per second. [Neglect friction.]



94. Calculate the height from which the sphere was released.

95. Calculate the magnitude of the centripetal force on the sphere as it passes through the lowest point in its swing.

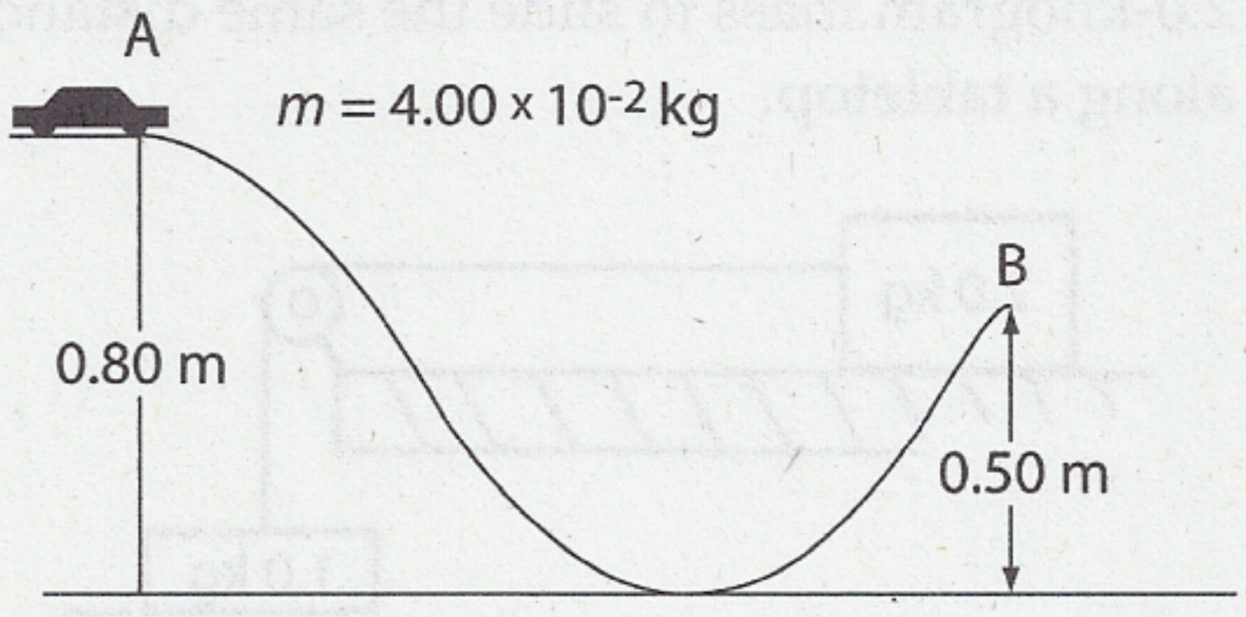
96. The magnitude of the centripetal force on the sphere could be halved as it passes through the lowest point in its swing by doubling the

(1) weight of the sphere, only
(2) length of the string, only
(3) height *h* and the weight of the sphere
(4) the length of the string and height *h*

97. Compared to the sphere's speed through the lowest point of its swing when released from *h*, the sphere's speed through the lowest point when released from 2*h* would be

(1) lower (2) greater (3) the same

98. In the diagram below, a toy car having a mass of 4.00×10^{-2} kilogram starts from rest at point *A* and travels 3.60 meters along a uniform track until coming to rest at point *B*.

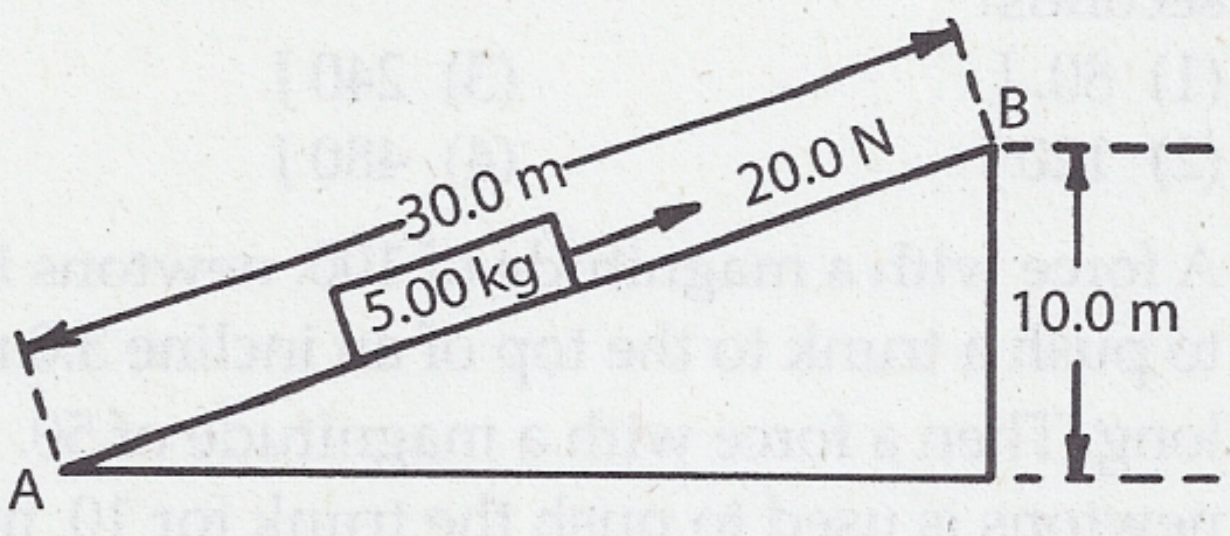


Calculate the magnitude of the frictional force acting on the car. [Assume the frictional force is constant.]

99. A car has a mass of 1.00×10^{3} kilograms. Calculate the work done in moving the car at constant speed a distance of 250 meters along a horizontal asphalt-paved road.

Base your answers to questions 100 and 101 on the information and diagram below.

A 20.0-newton force is needed to pull a 5.00-kilogram object up a hill at a constant speed of 2.0 meters per second.



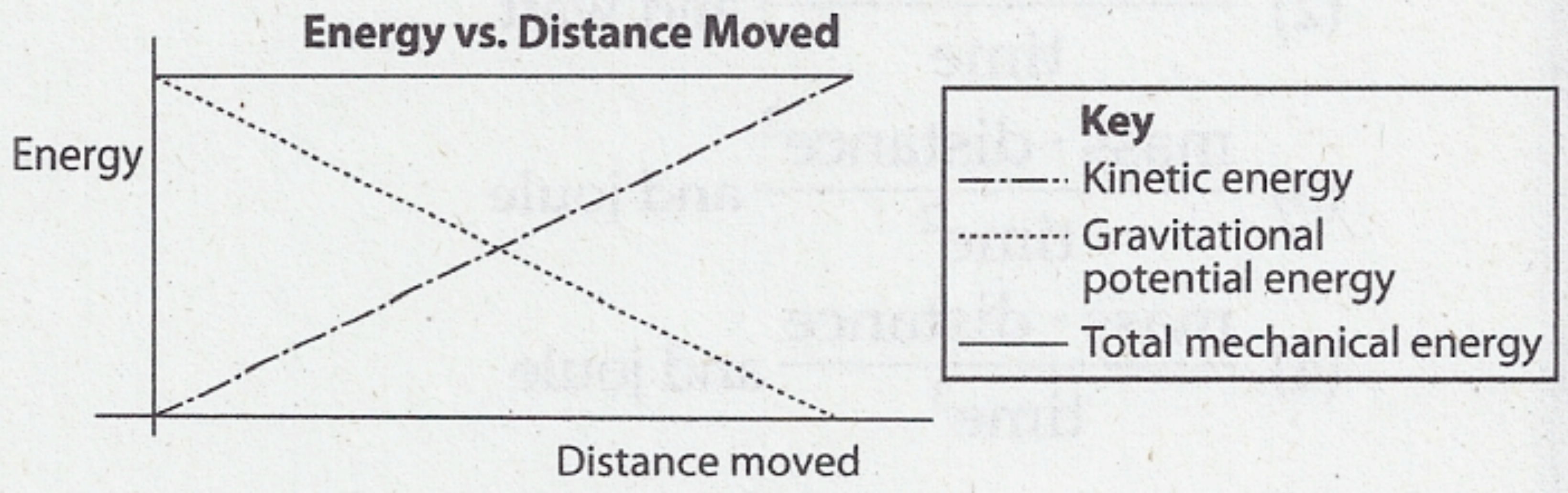
100. Determine the work done against gravity in moving the object from point *A* to point *B*.

101. Determine the work done against friction in moving the object from point *A* to point *B*.

102. As a block slides across a table, its speed decreases while its temperature increases. Which two changes occur in the block's energy as it slides?

(1) a decrease in kinetic energy and an increase in internal energy
(2) an increase in kinetic energy and a decrease in internal energy
(3) a decrease in both kinetic energy and internal energy
(4) an increase in both kinetic energy and internal energy

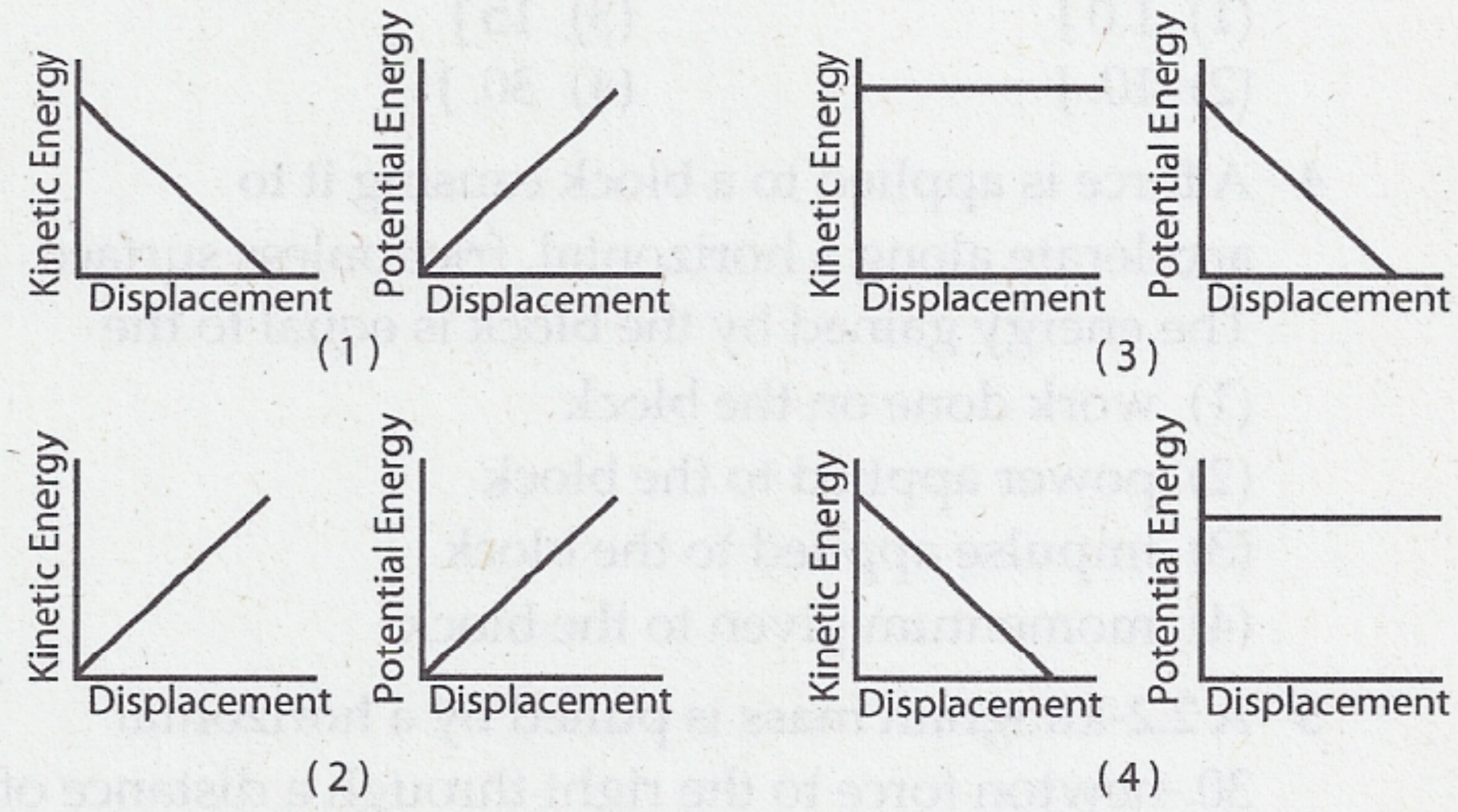
103. The graph below represents the kinetic energy, gravitational potential energy, and total mechanical energy of a moving block.



Which best describes the motion of the block?

(1) accelerating on a flat horizontal surface
(2) sliding up a frictionless incline
(3) falling freely
(4) being lifted at constant velocity

104. An object is thrown vertically upward. Which pair of graphs best represents the object's kinetic energy and gravitational potential energy as functions of its displacement while it rises?



Practice Questions *for the* New York Regents Exam

Directions

Review the Test-Taking Strategies section of this book. Then answer the following questions. Read each question carefully and answer with a correct choice or response.

Part A

1 Which variable expression is correctly paired with its corresponding unit?

(1) $\frac{\text{mass} \cdot \text{distance}}{\text{time}}$ and watt

(2) $\frac{\text{mass} \cdot \text{distance}^2}{\text{time}}$ and watt

(3) $\frac{\text{mass} \cdot \text{distance}^2}{\text{time}^2}$ and joule

(4) $\frac{\text{mass} \cdot \text{distance}}{\text{time}^3}$ and joule

2 What is an essential characteristic of an object in equilibrium?

(1) zero velocity
(2) zero acceleration
(3) zero potential energy
(4) zero kinetic energy

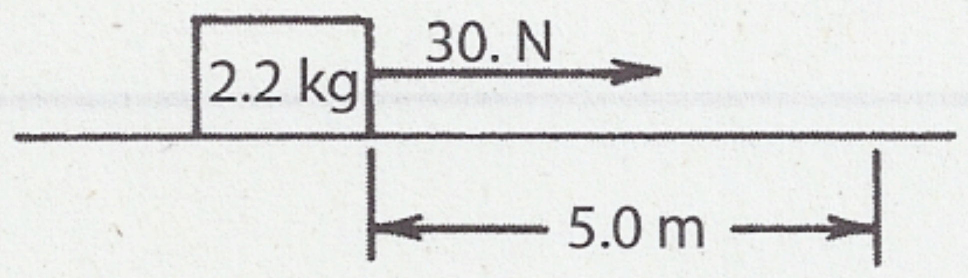
3 A net force with a magnitude of 5.0 newtons moves a 2.0-kilogram object a distance of 3.0 meters in 3.0 seconds. What is the total work done on the object?

(1) 1.0 J
(2) 10. J
(3) 15 J
(4) 30. J

4 A force is applied to a block causing it to accelerate along a horizontal, frictionless surface. The energy gained by the block is equal to the

(1) work done on the block
(2) power applied to the block
(3) impulse applied to the block
(4) momentum given to the block

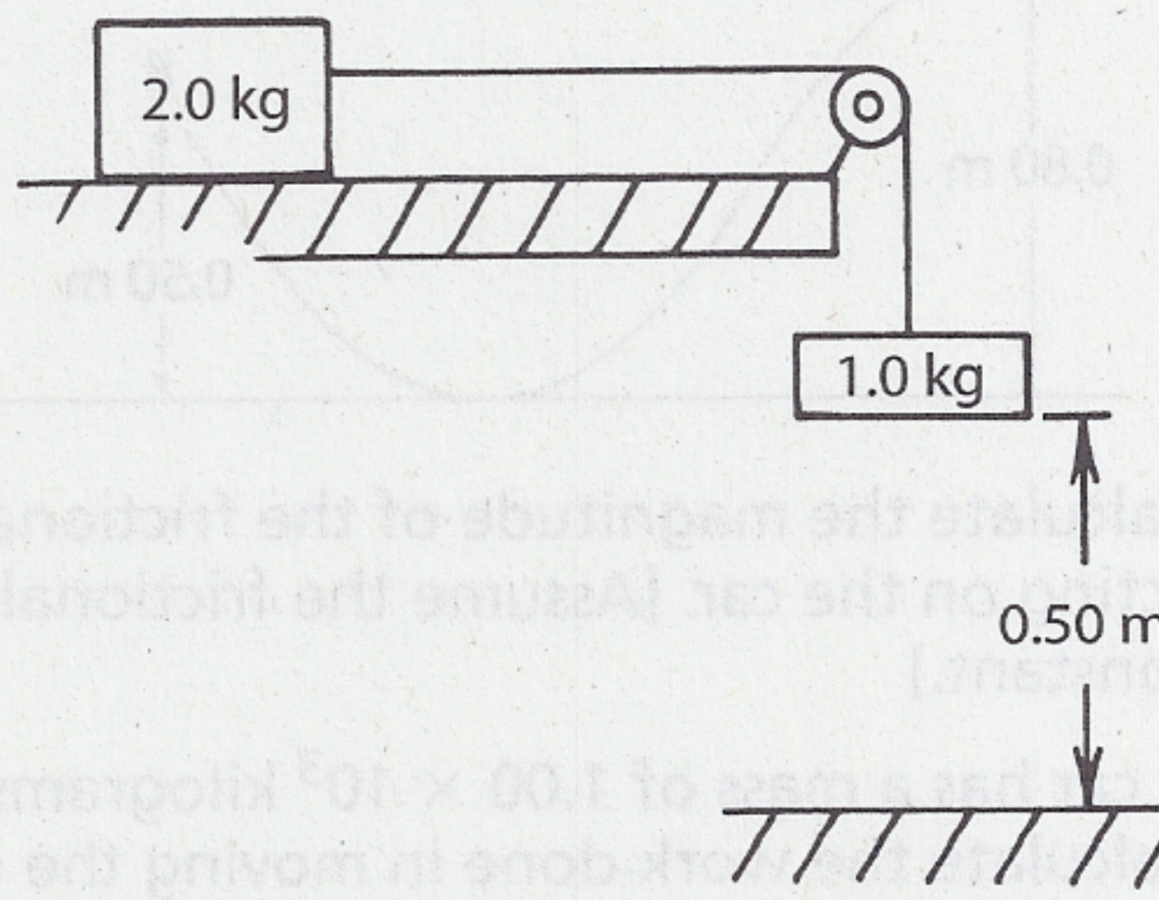
5 A 2.2-kilogram mass is pulled by a horizontal 30.-newton force to the right through a distance of 5.0 meters as shown in the diagram below.



What is the total amount of work done on the mass?

(1) 11 J
(2) 66 J
(3) 150 J
(4) 330 J

6 In the diagram below, a 1.0-kilogram mass falls a vertical distance of 0.50 meter, causing a 2.0-kilogram mass to slide the same distance along a tabletop.



What is the total work done by the falling mass?

(1) 1.5 J
(2) 4.9 J
(3) 9.8 J
(4) 15 J

7 A horizontal force with a magnitude of 40. newtons is used to push a block along a level table at a constant speed of 2.0 meters per second. How much work is done on the block in 6.0 seconds?

(1) 80. J
(2) 120 J
(3) 240 J
(4) 480 J

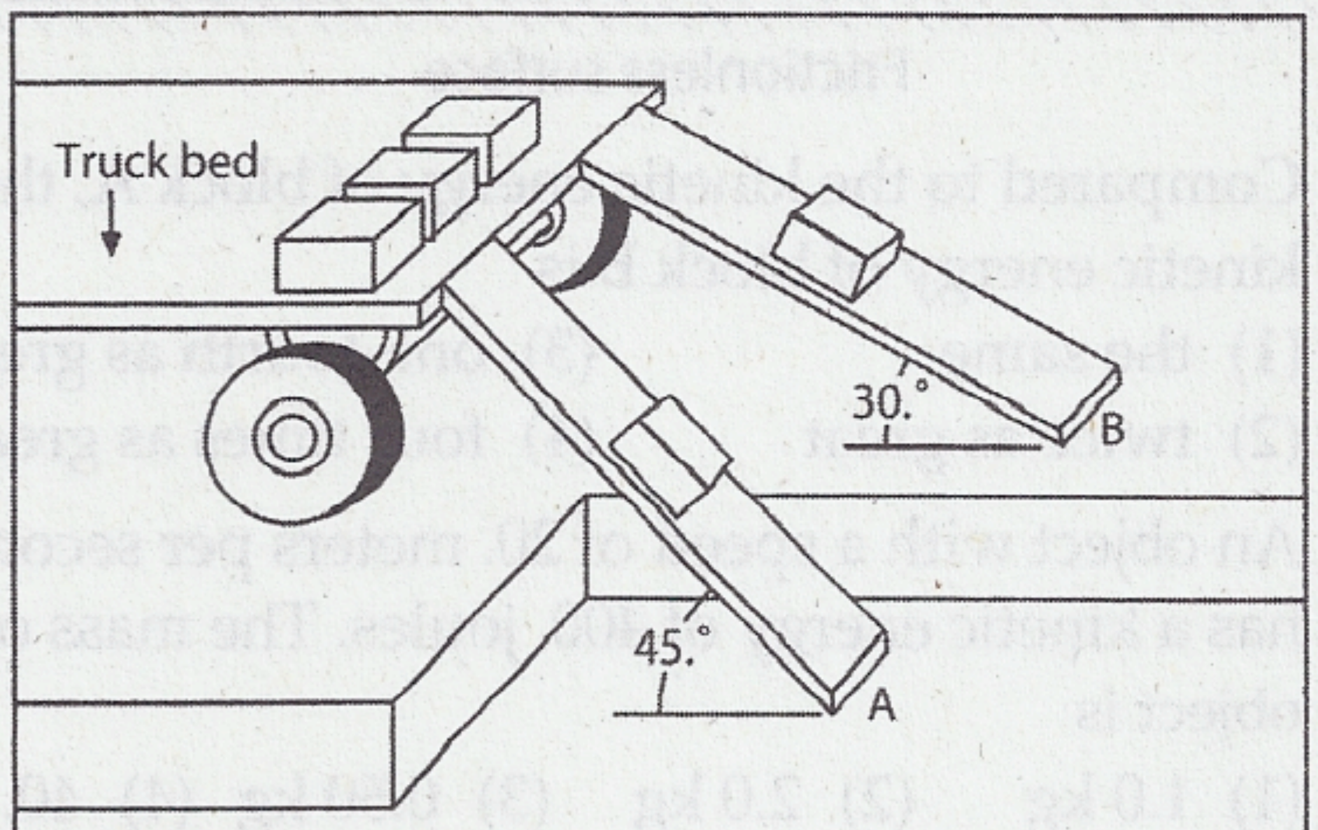
8 A force with a magnitude of 100. newtons is used to push a trunk to the top of an incline 3.0 meters long. Then a force with a magnitude of 50. newtons is used to push the trunk for 10. meters along a horizontal platform. What is the total work done on the trunk?

(1) 8.0×10^2 J
(2) 5.0×10^2 J
(3) 3.0×10^2 J
(4) 9.0×10^2 J

9 The amount of work done against friction to slide a box in a straight line across a uniform, horizontal floor depends most on the

(1) time taken to move the box
(2) distance the box is moved
(3) speed of the box
(4) direction of the box's motion

10 The diagram below shows two identical wooden planks, A and B, at different incline angles. The planks are used to slide concrete blocks from the bed of a truck.



Compared to the amount of work done against friction by a block sliding down plank A, the work done against friction by a block sliding down plank B is

(1) less
(2) more
(3) the same

11 A 95-kilogram student climbs 4.0 meters up a rope in 3.0 seconds. What is the power output of the student?

(1) 1.3×10^2 W
(2) 3.8×10^2 W
(3) 1.2×10^3 W
(4) 3.7×10^3 W

12 What is the minimum power required for a conveyor to raise an 8.0-newton box 4.0 meters vertically in 8.0 seconds?

(1) 260 W
(2) 64 W
(3) 32 W
(4) 4.0 W

13 A weightlifter lifts a 200-kilogram mass a vertical distance of 0.5 meter in 0.1 second. What is the lifter's power output?

(1) 1×10^{-4} W
(2) 4×10^{-4} W
(3) 1×10^4 W
(4) 4×10^4 W

14 A 4.0×10^3-watt motor applies an 8.0×10^2-newton force to move a boat at constant speed. How far does the boat move in 16 seconds?

(1) 3.2 m (2) 5.0 m (3) 32 m (4) 80. m

15 A boat weighing 9.0×10^2 newtons requires a horizontal force of 6.0×10^2 newtons to move it across the water at 1.5×10^1 meters per second. The boat's engine must provide energy at the rate of

(1) 2.5×10^{-2} J
(2) 4.0×10^1 W
(3) 7.5×10^3 J
(4) 9.0×10^3 W

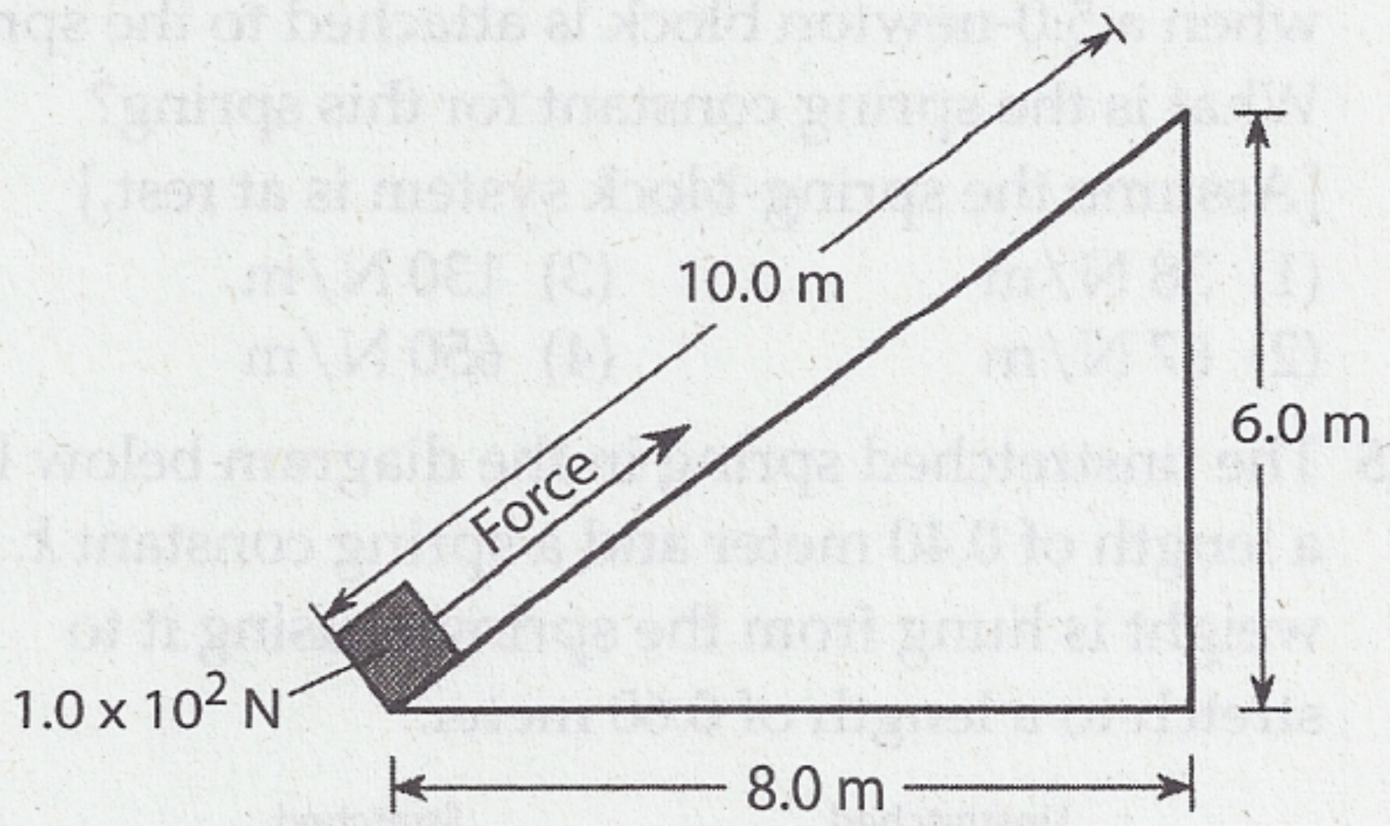
16 As a ball falls freely toward the ground, what happens to the ball's speed and gravitational potential energy with respect to the ground?

(1) Both speed and gravitational potential energy decrease.
(2) Speed decreases and gravitational potential energy increases.
(3) Speed increases and gravitational potential energy decreases.
(4) Both speed and gravitational potential energy increase.

17 An object of mass m is lifted a vertical distance h above the surface of Earth at constant speed v in time t. The total gravitational potential energy with respect to Earth's surface gained by the object is equal to the

(1) average force applied to the object
(2) total weight of the object
(3) total work done on the object
(4) total momentum gained by the object

18 A box weighing 1.0×10^2 newtons is dragged to the top of an incline, as shown in the diagram below.



With respect to the bottom of the incline, the gravitational potential energy of the box at the top of the incline is

(1) 1.0×10^2 J
(2) 6.0×10^2 J
(3) 8.0×10^2 J
(4) 1.0×10^3 J

19 What is the spring constant of a spring of negligible mass that gains 6.0 joules of elastic potential energy as a result of being compressed 0.40 meter?

(1) 2.4 N/m
(2) 15 N/m
(3) 38 N/m
(4) 75 N/m

20 Spring A has a spring constant of 140 newtons per meter and spring B has a spring constant of 280 newtons per meter. Both springs are stretched the same distance. Compared to the elastic potential energy stored in spring A, the elastic potential energy stored in spring B is
(1) the same (3) half as great
(2) twice as great (4) four times as great

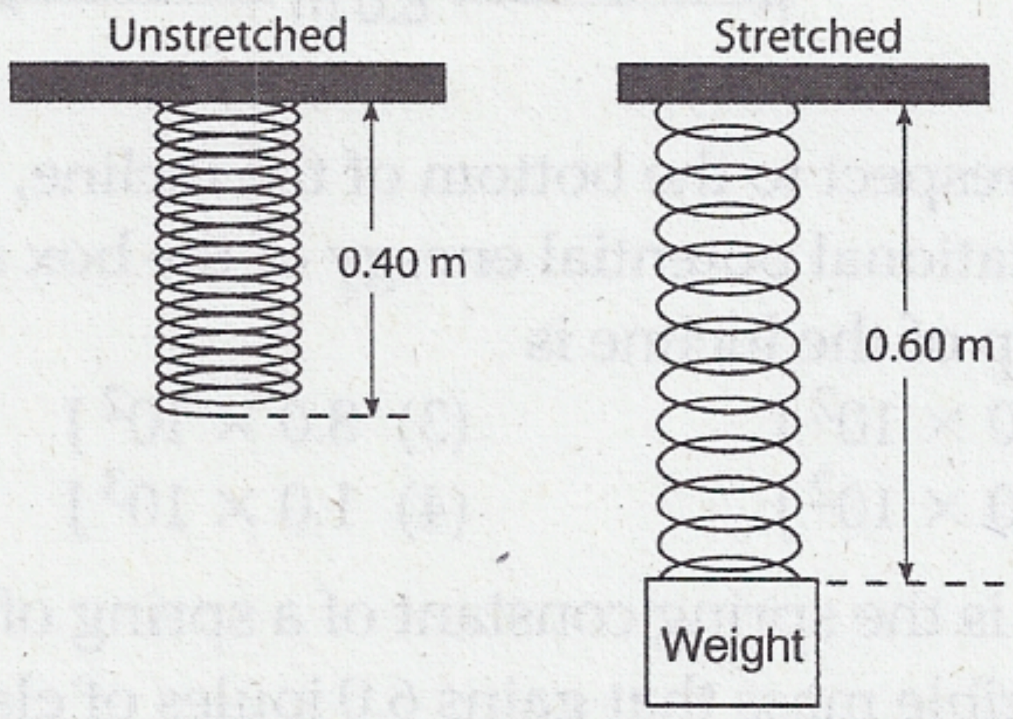
21 A vertical spring 0.100 meter long is elongated to a length of 0.119 meter when a 1.00-kilogram mass is attached to the bottom of the spring. The spring constant of this spring is
(1) 9.8 N/m (3) 98 N/m
(2) 82 N/m (4) 520 N/m

22 A force with a magnitude of 10. newtons is required to hold a stretched spring 0.20 meter from its rest position. What is the elastic potential energy stored in the stretched spring?
(1) 1.0 J (2) 2.0 J (3) 5.0 J (4) 50. J

23 When a mass is placed on a spring with a spring constant of 15 newtons per meter, the spring is compressed 0.25 meter. How much elastic potential energy is stored in the spring?
(1) 0.47 J (2) 0.94 J (3) 1.9 J (4) 3.8 J

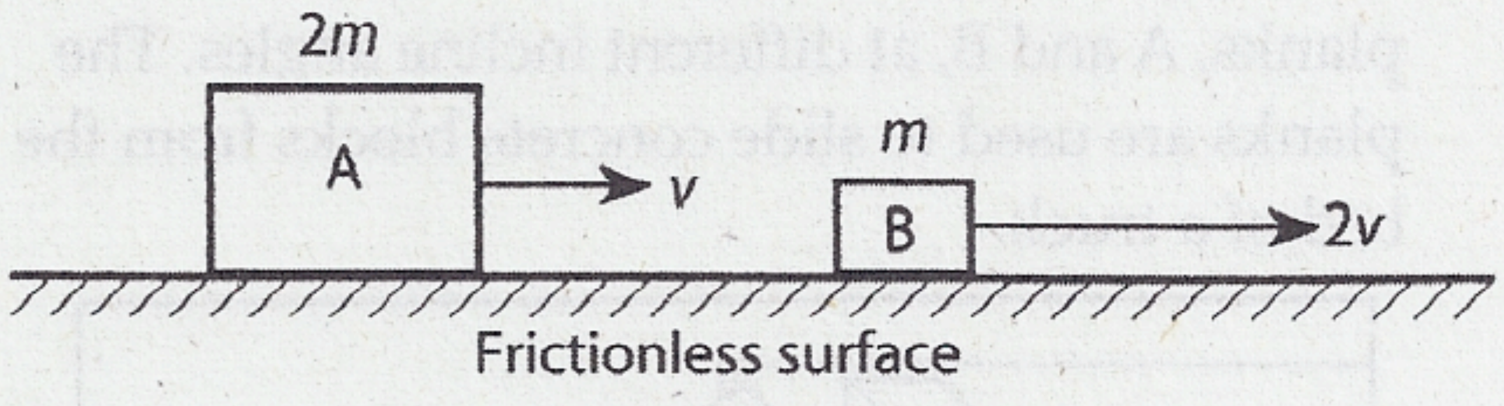
24 A vertically hung spring stretches 0.075 meter when a 5.0-newton block is attached to the spring. What is the spring constant for this spring? [Assume the spring-block system is at rest.]
(1) 38 N/m (3) 130 N/m
(2) 67 N/m (4) 650 N/m

25 The unstretched spring in the diagram below has a length of 0.40 meter and a spring constant k. A weight is hung from the spring causing it to stretch to a length of 0.60 meter.



How many joules of elastic potential energy are stored in this stretched spring?
(1) $0.020 \times k$ (3) $0.18 \times k$
(2) $0.080 \times k$ (4) $2.0 \times k$

26 The diagram below shows block A having mass $2m$ and speed v, and block B having mass m and speed $2v$.



Compared to the kinetic energy of block A, the kinetic energy of block B is
(1) the same (3) one-fourth as great
(2) twice as great (4) four times as great

27 An object with a speed of 20. meters per second has a kinetic energy of 400. joules. The mass of the object is
(1) 1.0 kg (2) 2.0 kg (3) 0.50 kg (4) 40. kg

28 A total of 10.0 joules of work is done in accelerating a 20.-newton object from rest across a horizontal frictionless table. What is the total kinetic energy gained by the object?
(1) 0.0 J (2) 2.0 J (3) 10. J (4) 200 J

29 A baseball bat strikes a ball with a force with a magnitude of 2.0×10^4 newtons. If the bat stays in contact with the ball for a distance of 5.0×10^{-3} meter, what kinetic energy will the ball acquire from the bat?
(1) 1.0×10^2 J (3) 2.5×10^1 J
(2) 2.0×10^2 J (4) 4.0×10^2 J

30 An object 8 meters above the ground has Z joules of gravitational potential energy with respect to the ground. If the object falls freely, how many joules of kinetic energy will it have gained when it is 4 meters above the ground?
(1) Z (2) $2Z$ (3) $\frac{Z}{2}$ (4) 0

31 A girl rides an escalator that moves her upward at constant speed. As the girl rises, how do her kinetic energy and gravitational potential energy with respect to the bottom of the escalator change?
(1) Kinetic energy decreases and potential energy decreases.
(2) Kinetic energy decreases and potential energy increases.
(3) Kinetic energy remains the same and potential energy decreases.
(4) Kinetic energy remains the same and potential energy increases.

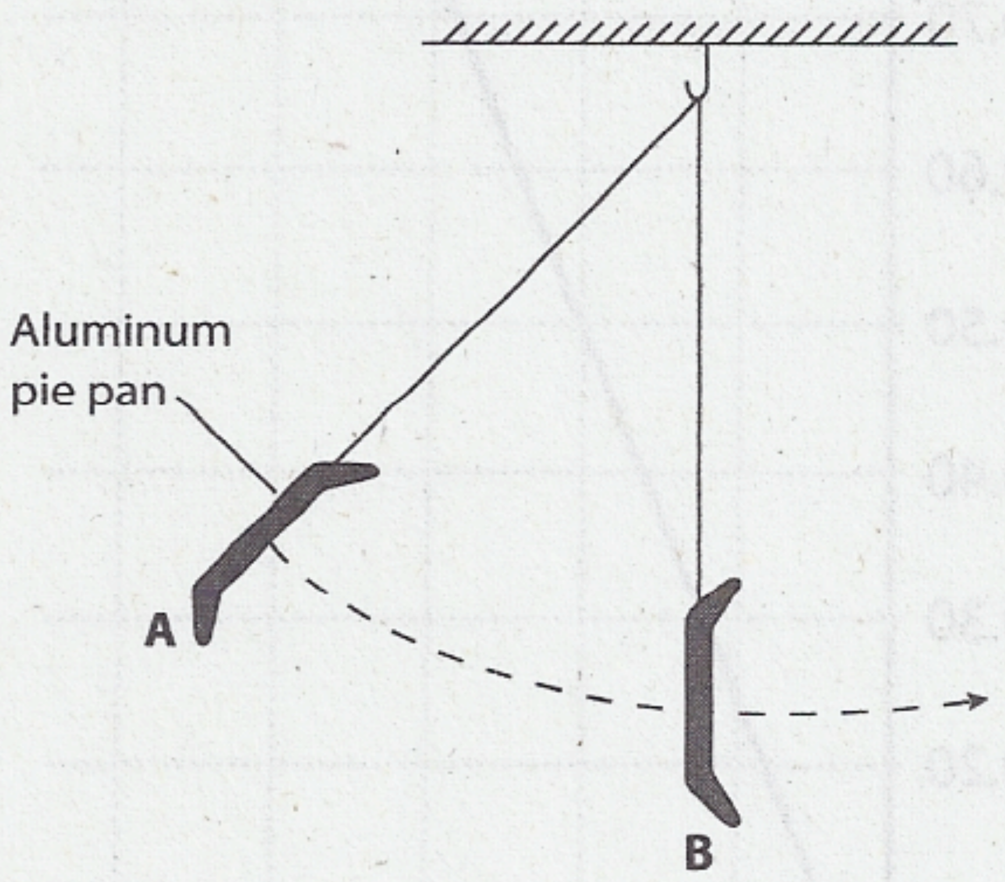
32 A 0.10-kilogram ball dropped vertically from a height of 1.00 meter above the floor bounces back to a height of 0.80 meter. The mechanical energy "lost" by the ball as it bounces is

(1) 0.020 J
(2) 0.20 J
(3) 0.78 J
(4) 0.98 J

33 A stone is dropped in air from a height of 50 meters above the ground. As the stone falls, what happens to the stone's kinetic energy and internal energy?

(1) Kinetic energy decreases and internal energy decreases.
(2) Kinetic energy decreases and internal energy increases.
(3) Kinetic energy increases and internal energy decreases.
(4) Kinetic energy increases and internal energy increases.

34 An aluminum pie pan is attached to a string and suspended from a hook, as shown in the diagram below. The pan is released from position *A* and swings through the air to position *B*.



What is the relationship between the kinetic energy at position *B*, KE_B, and the gravitational potential energy at position *A*, PE_A with respect to *B*?

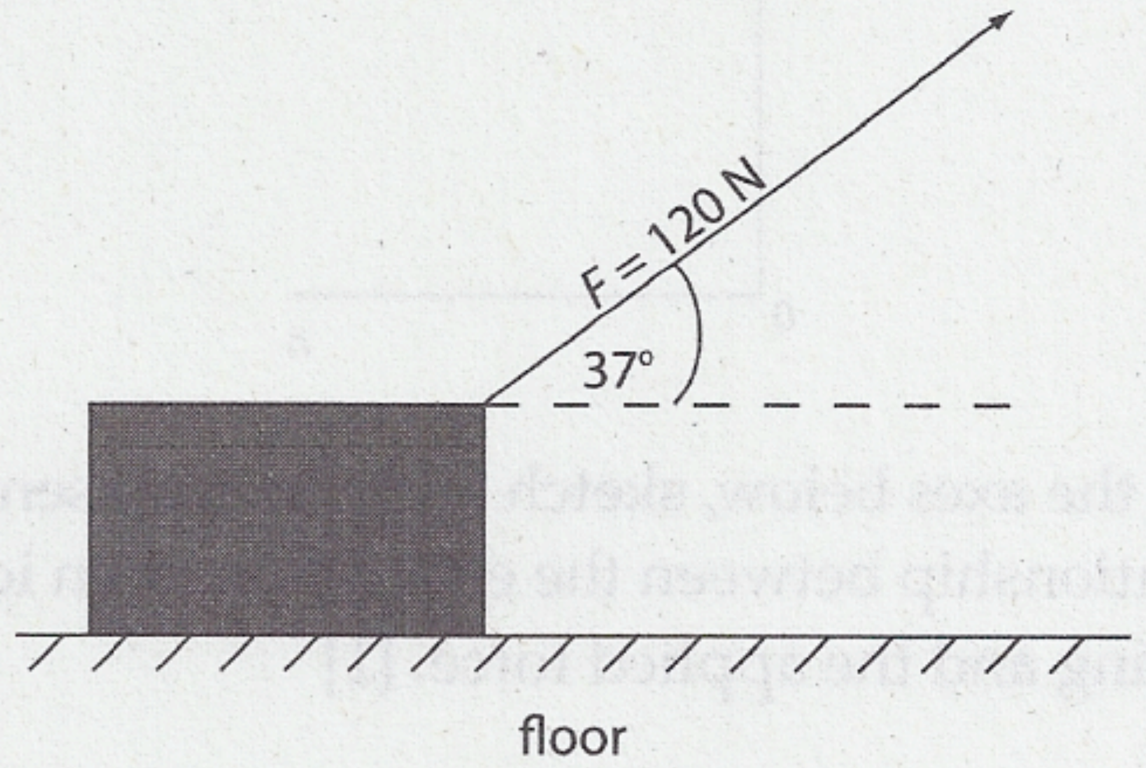
(1) KE_B is equal to PE_A minus work done against friction.
(2) KE_B is equal to the PE_A plus work done against friction.
(3) KE_B is equal to PE_A.
(4) KE_B is equal to $2PE_A$.

35 The bottom of a heavy block is covered with sandpaper. The block is repeatedly slid 1.0 meter at constant speed across a uniform, horizontal wooden plank by the application of a constant horizontal force. As the coefficient of friction between the sandpaper and the plank decreases, the amount of work done in sliding the block 1.0 meter along the plank at constant speed

(1) decreases
(2) increases
(3) remains the same

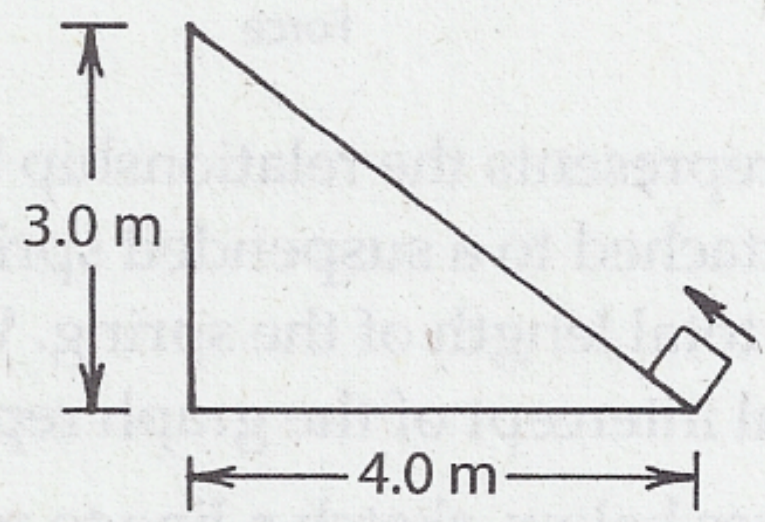
Part B

36 In the diagram below, a box is pulled at constant speed across the floor by the application of a constant force with a magnitude of 120 newtons acting at an angle of 37° to the horizontal.



Calculate the total work done in pulling the box 10. meters across the floor. [2]

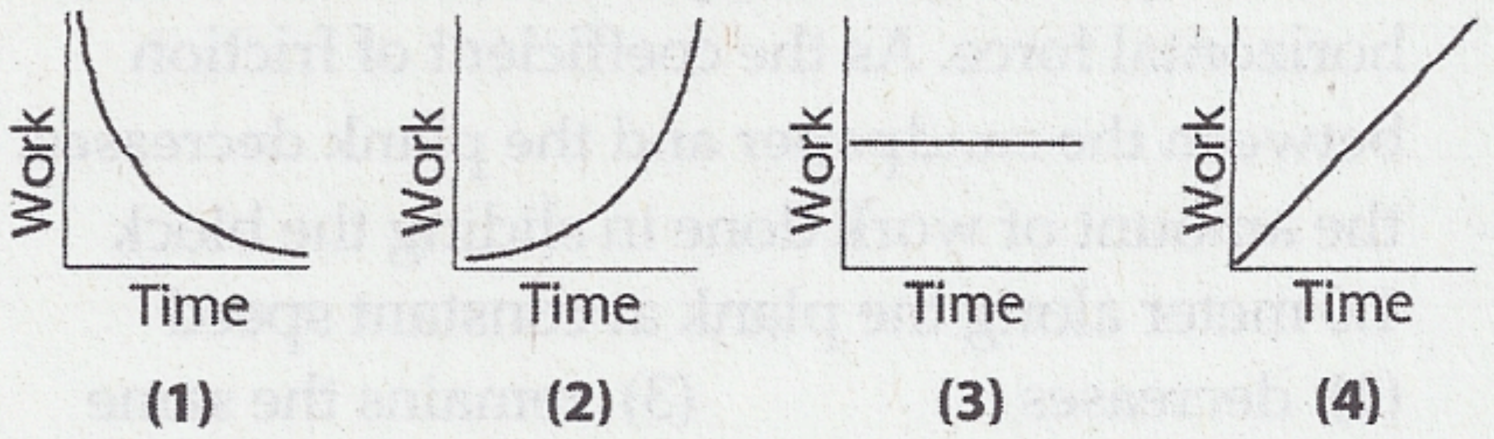
37 A 20.-newton block is at rest at the bottom of a frictionless incline, as shown in the diagram below.



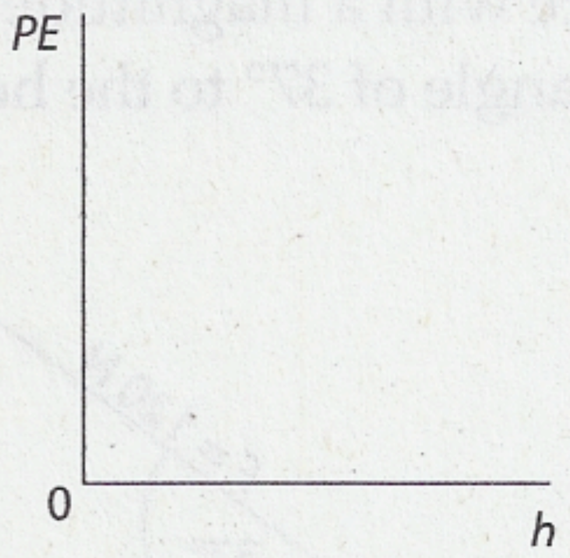
Calculate the work that must be done against gravity to move the block to the top of the incline. [2]

38 A student applies a constant horizontal force having a magnitude of 20. newtons to move a crate at a constant speed of 4.0 meters per second across a rough floor. Calculate the total work done by the student on the 80.-kilogram crate in 6.0 seconds. [3]

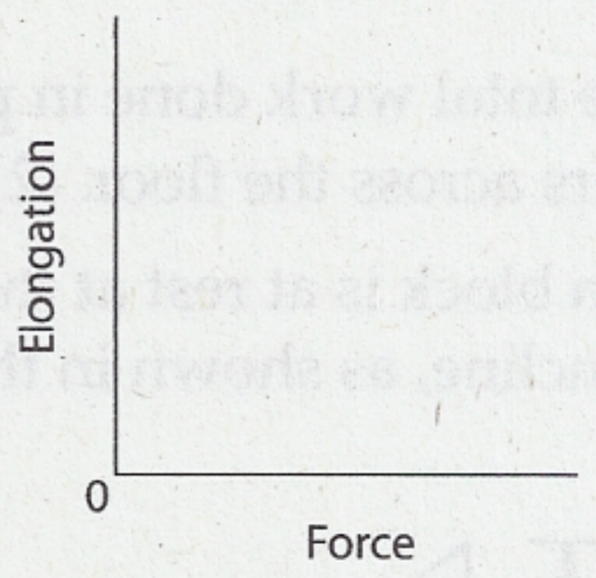
39 A student running up a flight of stairs increases her speed at a constant rate. Which graph best represents the relationship between work and time for the student's run up the stairs?



40 On the axes below, sketch a line to represent the relationship between gravitational potential energy *PE* with respect to the ground and height *h* above the ground for an object near the surface of Earth. [1]

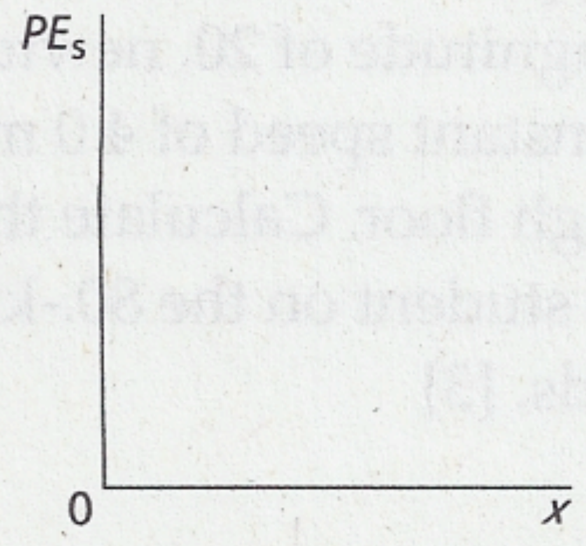


41 On the axes below, sketch a line to represent the relationship between the elongation of an ideal spring and the applied force. [1]

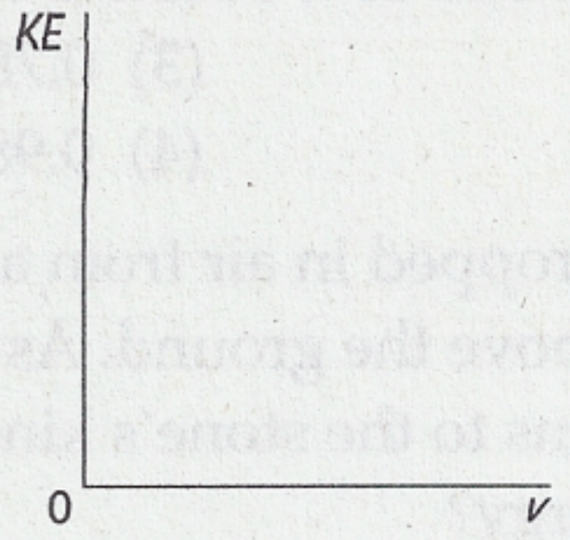


42 A graph represents the relationship between the weight attached to a suspended spring and the resulting total length of the spring. What does the horizontal intercept of the graph represent? [1]

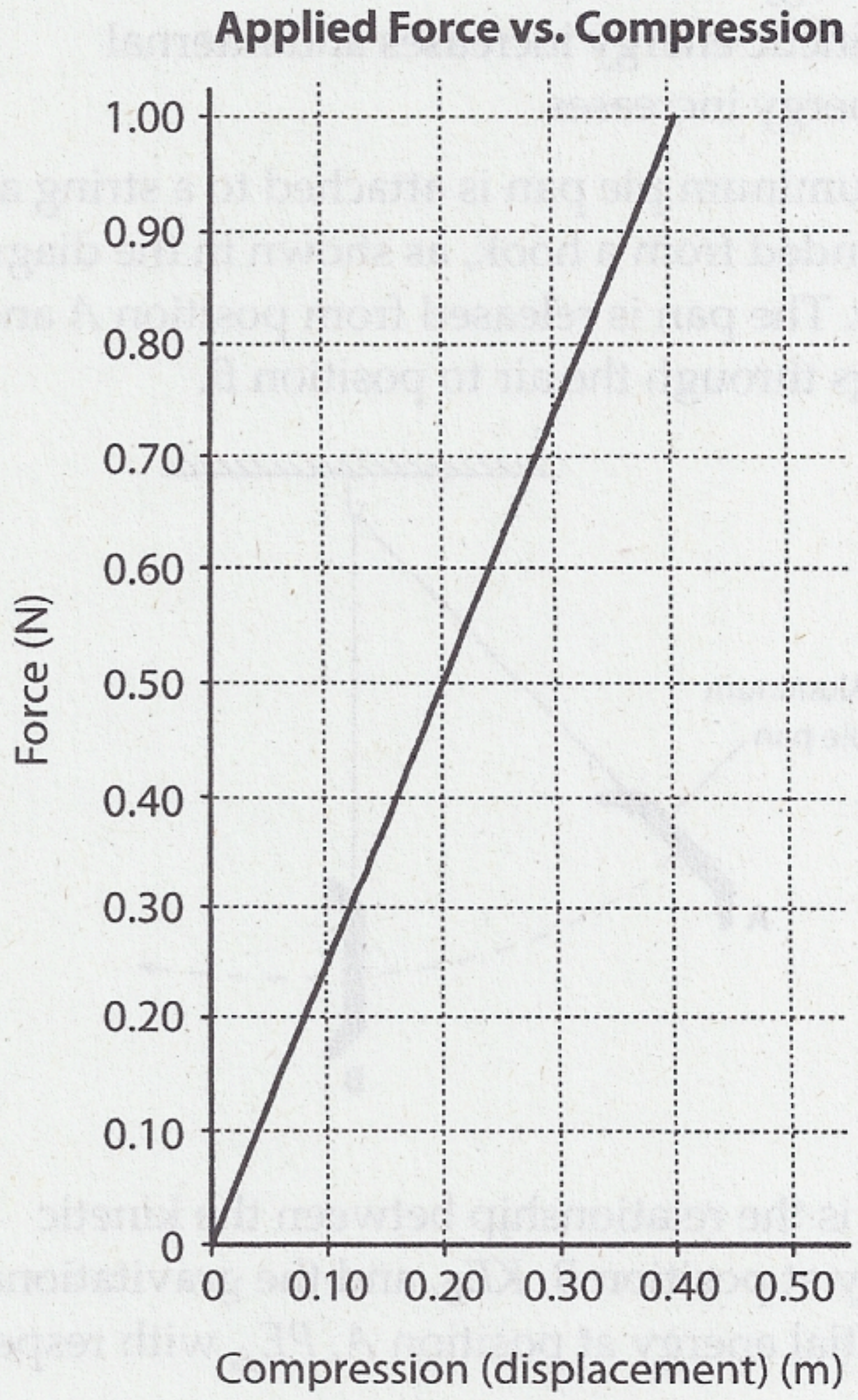
43 On the axes below, sketch a line to represent the relationship between the elastic potential energy stored in a spring PE_s and the change in the length of the spring from its equilibrium position *x*. [1]



44 On the axes below, sketch a line to represent the relationship between the kinetic energy *KE* of a moving object and its speed *v*. [1]



Base your answers to questions 45 through 47 on the graph below, which shows the relationship between the force applied to an ideal spring and the compression of the spring.

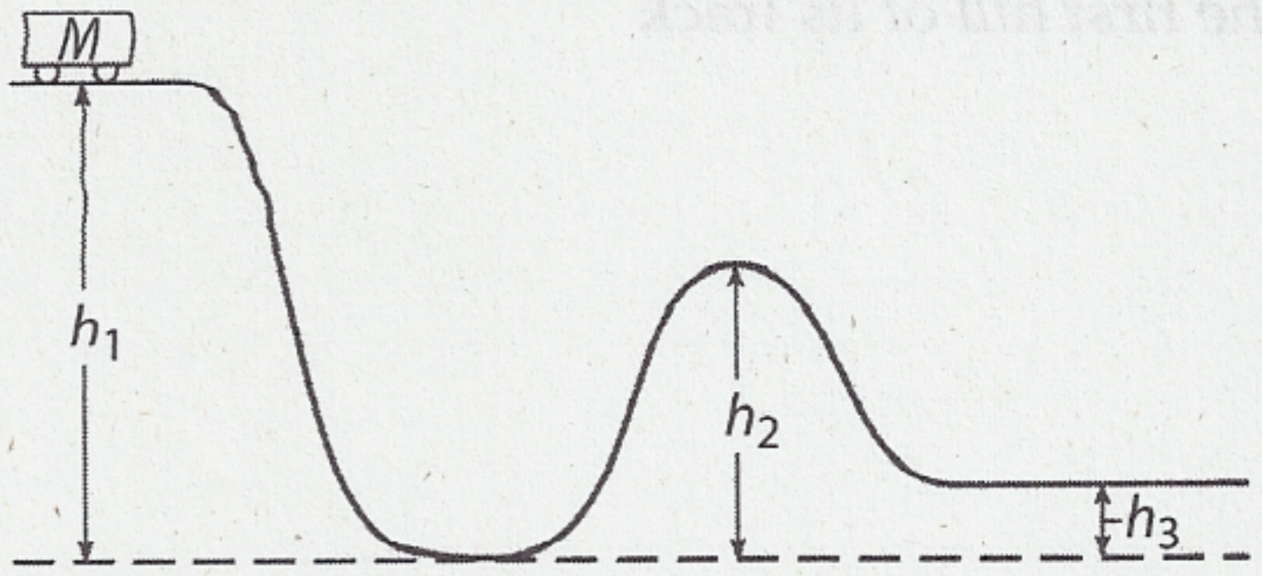


45 Calculate the spring constant for the spring. [2]

46 Calculate the elastic potential energy stored in the spring when it is compressed 0.20 meter. [2]

47 Determine the total work done in compressing the spring 0.20 meter. [1]

48 A cart of mass M on a frictionless track starts from rest at the top of a hill having height h_1, as shown in the diagram below.



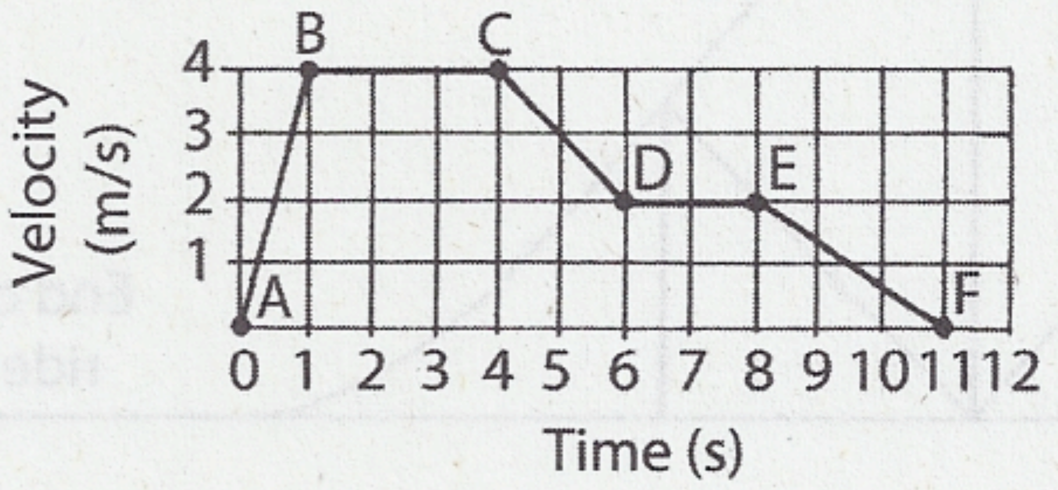
What is the kinetic energy of the cart when it reaches the top of the next hill h_2?

(1) Mgh_1
(2) $Mg(h_1 - h_2)$
(3) $Mg(h_2 - h_3)$
(4) 0

Base your answers to questions 49 through 53 on the information and graph below.

A 2.0-kilogram object moves along a horizontal frictionless surface. The graph shows the relationship between the object's velocity and elapsed time.

Velocity vs. Time



49 Calculate the distance the object moves during interval EF. [2]

50 What is the net force on the object during the interval DE? [1]

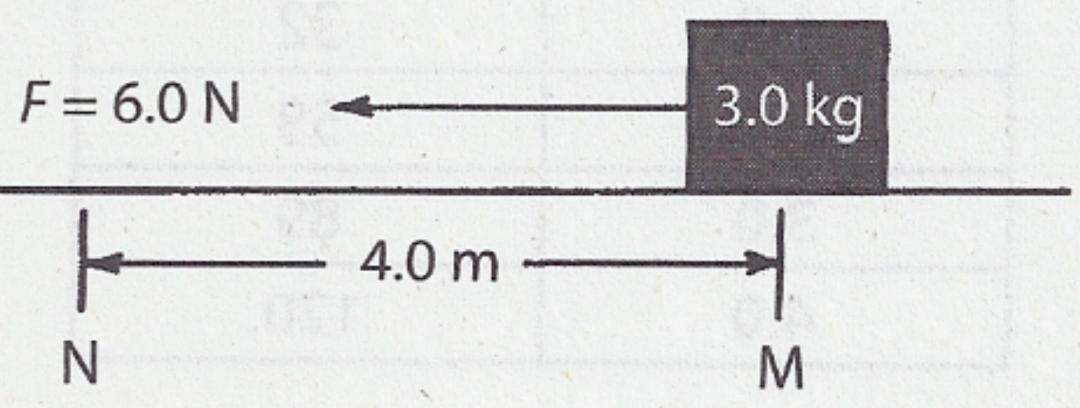
51 Calculate the magnitude of the momentum of the object during interval BC. [2]

52 Calculate the kinetic energy of the object during interval BC. [2]

53 Identify an interval during which work is *not* being done on the object. [1]

Base your answers to questions 54 through 58 on the information and diagram below.

A 3.0-kilogram mass is being moved at constant speed across a horizontal surface by a constant 6.0-newton horizontal force to the left.



54 What is the change in kinetic energy of the mass as it is moved from point M to point N? [1]

55 Calculate the total work done in 2.0 seconds if energy is supplied at a rate of 10.0 watts. [2]

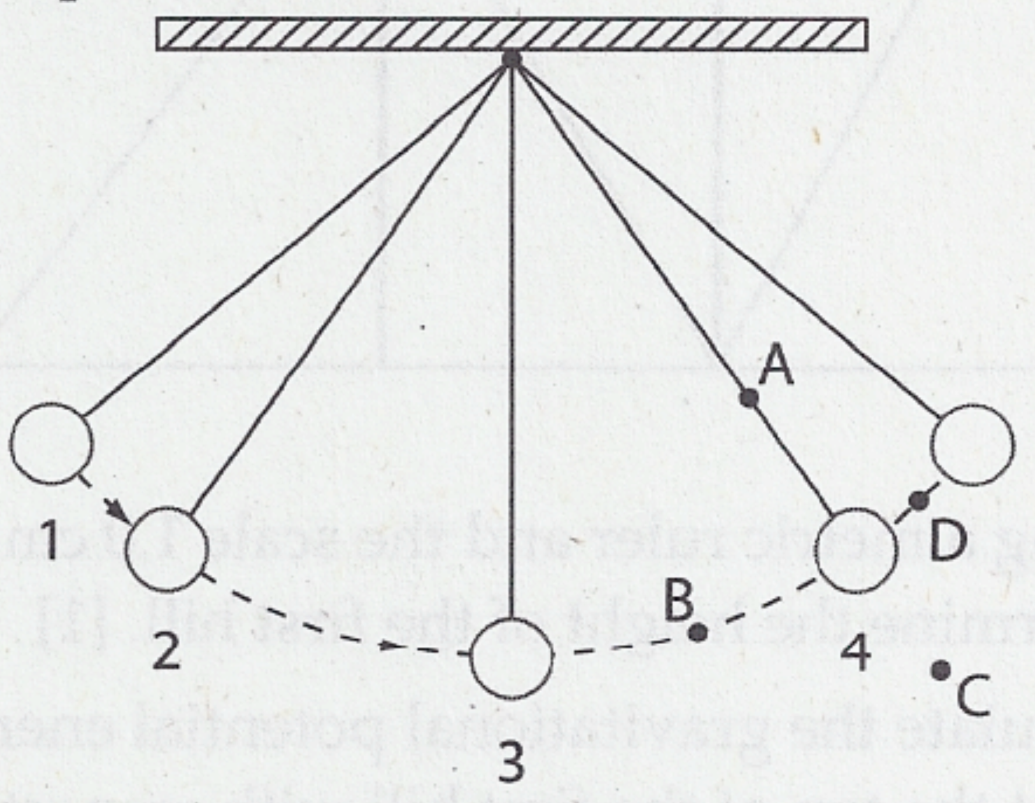
56 What is the magnitude of the force of friction acting on the mass? [1]

57 Calculate the magnitude of the acceleration that would be produced by the 6.0-newton force if the surface the mass slides on was frictionless. [2]

58 Calculate the gravitational potential energy of the 3.0-kilogram mass with respect to the horizontal surface if the mass was raised to a height of 4.0 meters. [2]

Base your answers to questions 59 through 63 on the information and diagram below.

A simple pendulum with a 2.00-kilogram bob and a length of 10.0 meters is released from rest at position 1 and swings without friction through position 4. At position 3, its lowest point, the speed of the bob is 6.00 meters per second.



59 At which point does the bob have its maximum kinetic energy? [1]

60 Calculate the gravitational potential energy of the bob at position 1 with respect to position 3. [2]

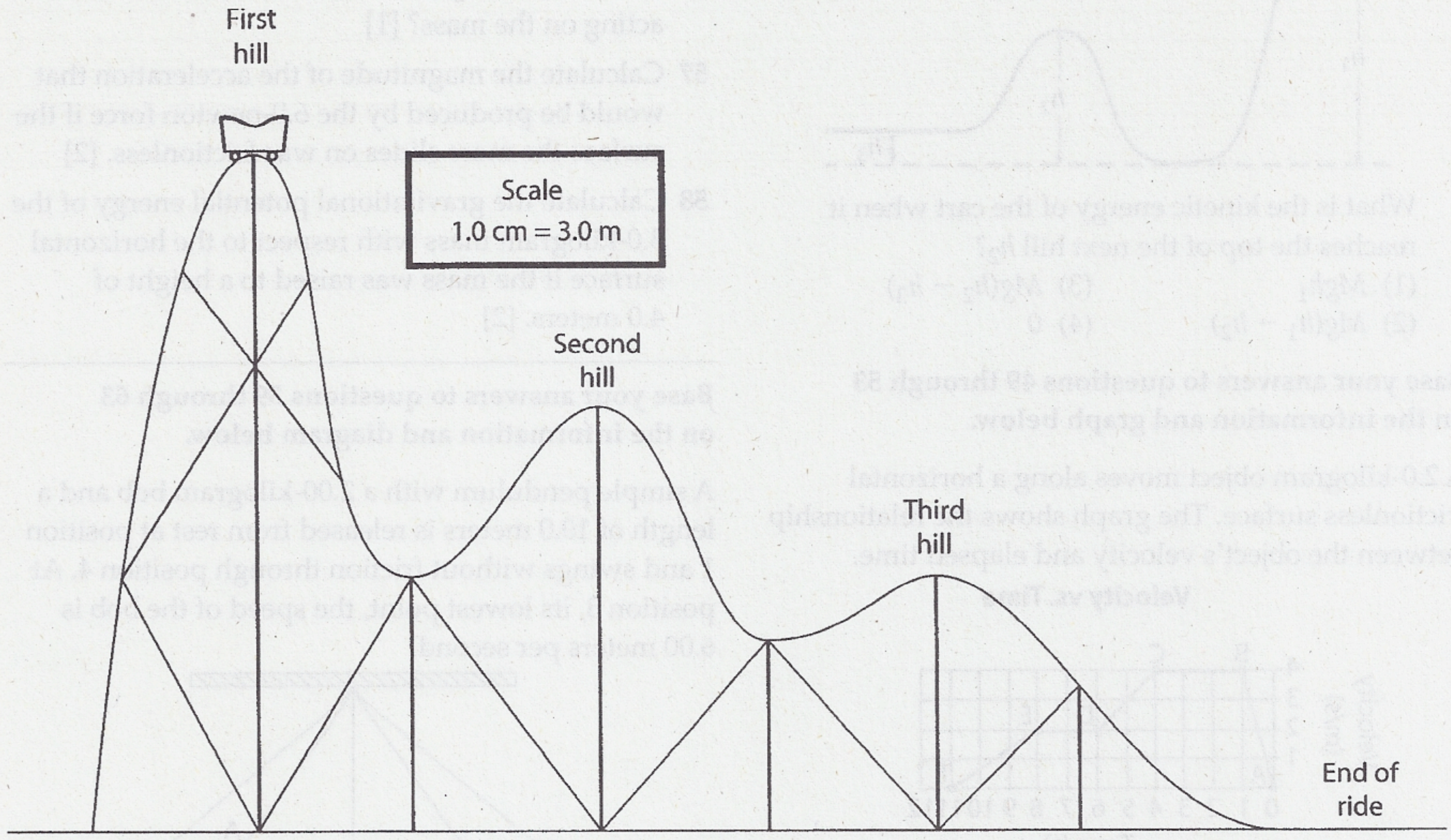
61 At position 4, toward which point, A, B, C, or D, is the centripetal force directed? [1]

62 Calculate the magnitude of the centripetal acceleration of the bob at position 3. [2]

63 Compare the sum of the kinetic and potential energies of the bob at position 1 (with respect to position 3) to the sum of the kinetic and potential energies of the bob at position 2 (again, with respect to position 3). [1]

Base your answers to questions 64 through 66 on the information and diagram below, which is drawn to a scale of 1.0 centimeter = 3.0 meters.

A 650-kilogram roller coaster car starts from rest at the top of the first hill of its track and glides freely. [Neglect friction.]



64 Using a metric ruler and the scale 1.0 cm = 3.0 m, determine the height of the first hill. [1]

65 Calculate the gravitational potential energy of the car at the top of the first hill with respect to the end of the ride. [2]

66 Compare the kinetic energy of the car at the top of the second hill to its kinetic energy at the top of the third hill. [1]

Base your answers to questions 67 through 70 on the information below.

A 6.00-kilogram concrete block is dropped from the top of a tall building. The block falls a distance of 55.0 meters and has a speed of 30.0 meters per second when it hits the ground.

67 Calculate the gravitational potential energy of the block with respect to the ground at the instant it is released. [2]

68 Calculate the kinetic energy of the block at the point of impact. [2]

69 Determine the total amount of mechanical energy "lost" by the block as it falls. [1]

70 Explain what happens to the mechanical energy that is "lost" by the block. [1]

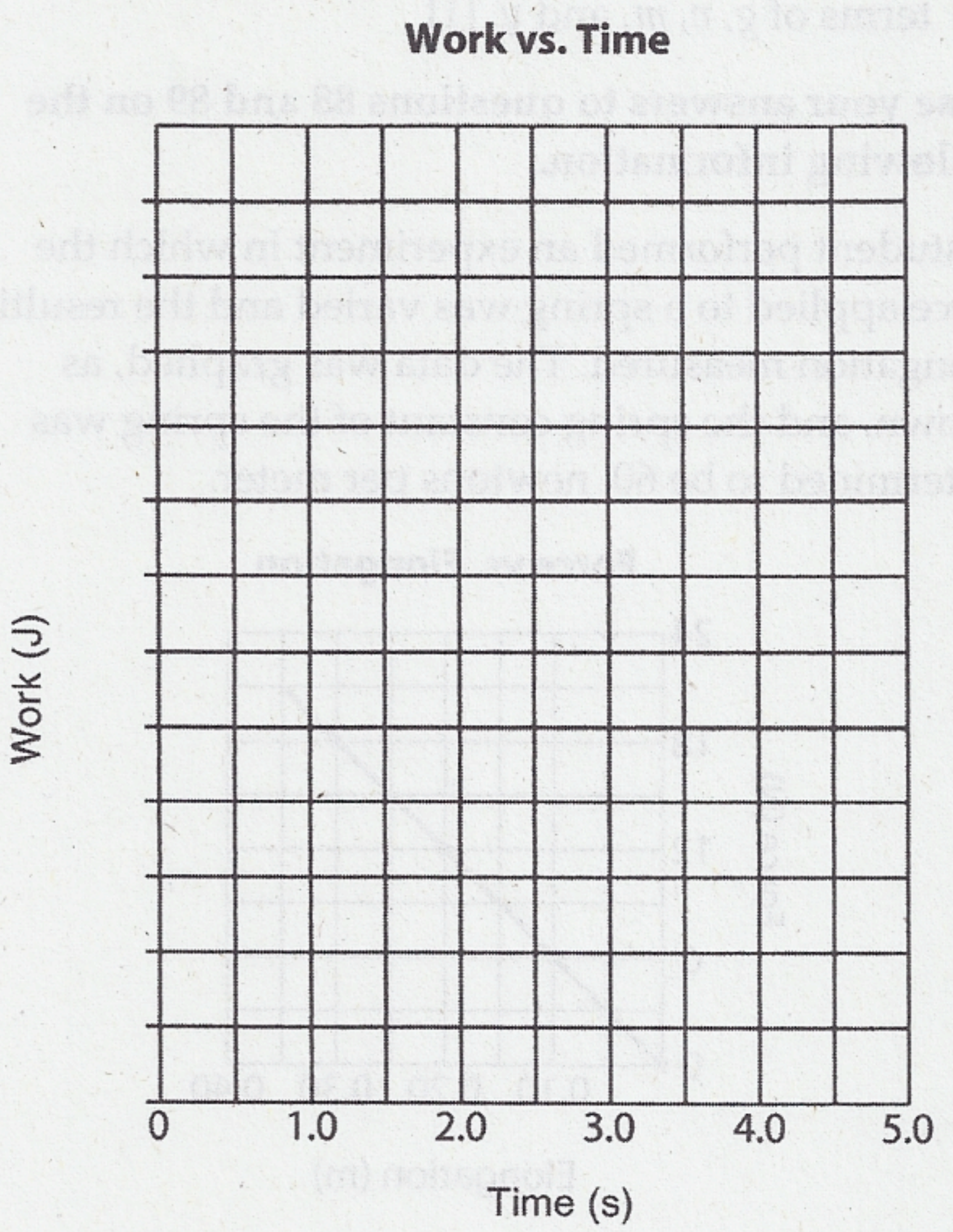
Base your answers to questions 71 through 74 on the information and data table below.

A student performs a laboratory activity in which a constant 15-newton force acts on a 2.0-kilogram mass. The work done over time is summarized in the data table.

Time (s)	Work (J)
0	0
1.0	32
2.0	59
3.0	89
4.0	120.

71 Using information in the data table, construct a graph on the grid provided following the directions below:

- Mark an appropriate scale on the axis labeled "Work (J)." [1]
- Plot the data points. [1]
- Draw the best-fit line. [1]



72 Calculate the slope of the line of best fit. [2]

73 What is the physical significance of the slope of the graph? [1]

74 Based on your graph, how much time did it take to do 75 joules of work? [1]

Base your answers to questions 75 through 77 on your knowledge of physics.

75 Explain why it requires more work to stop a ferry boat than a canoe if both are originally traveling with the same velocity. [1]

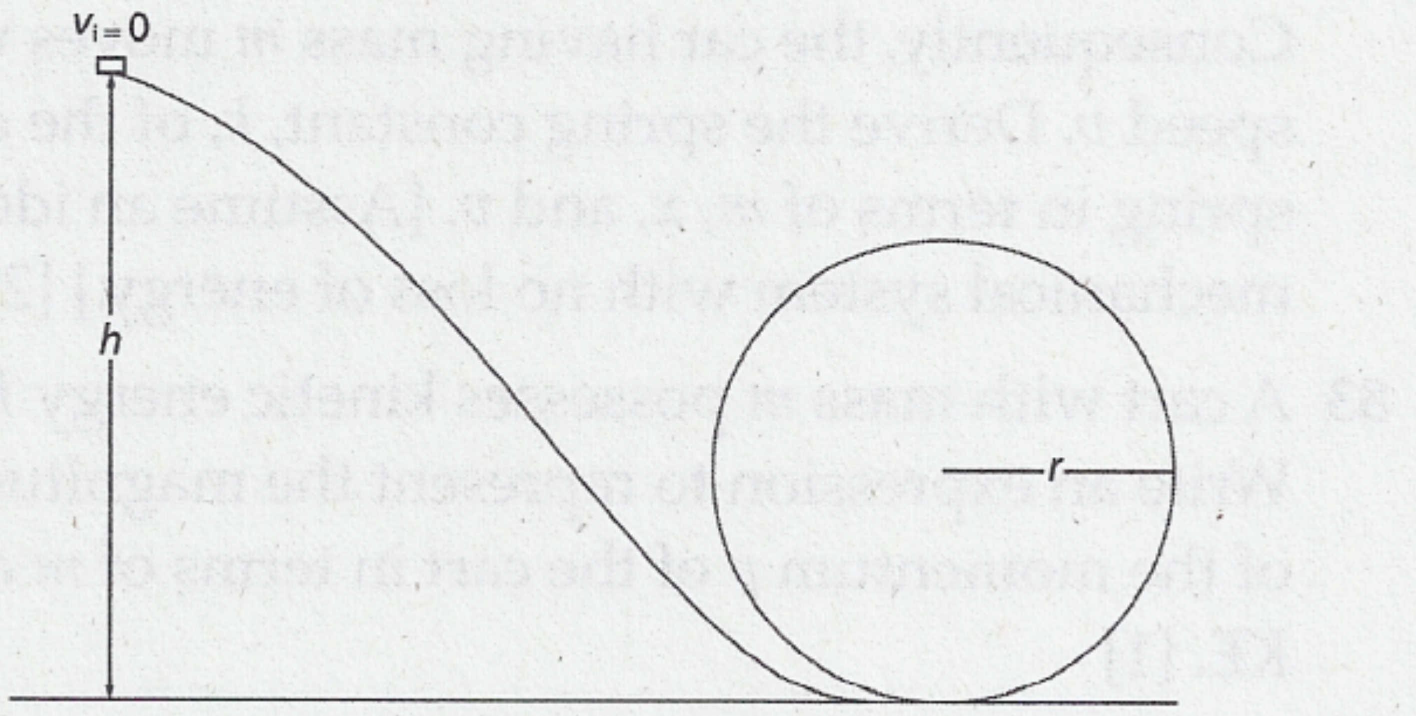
76 A 2.0-kilogram ball is used as the bob of a pendulum suspended from the ceiling of a classroom. The bob is drawn from its equilibrium position and released from the tip of a student's nose. Explain why, if the student does not move, there is no danger of the student being struck on the return swing. [1]

77 A 700.-newton physics teacher runs at constant speed up a flight of stairs rising 6.0 meters in 7.0 seconds. Explain why the teacher can claim he is more powerful than five 100-watt incandescent light bulbs. [1]

Part C

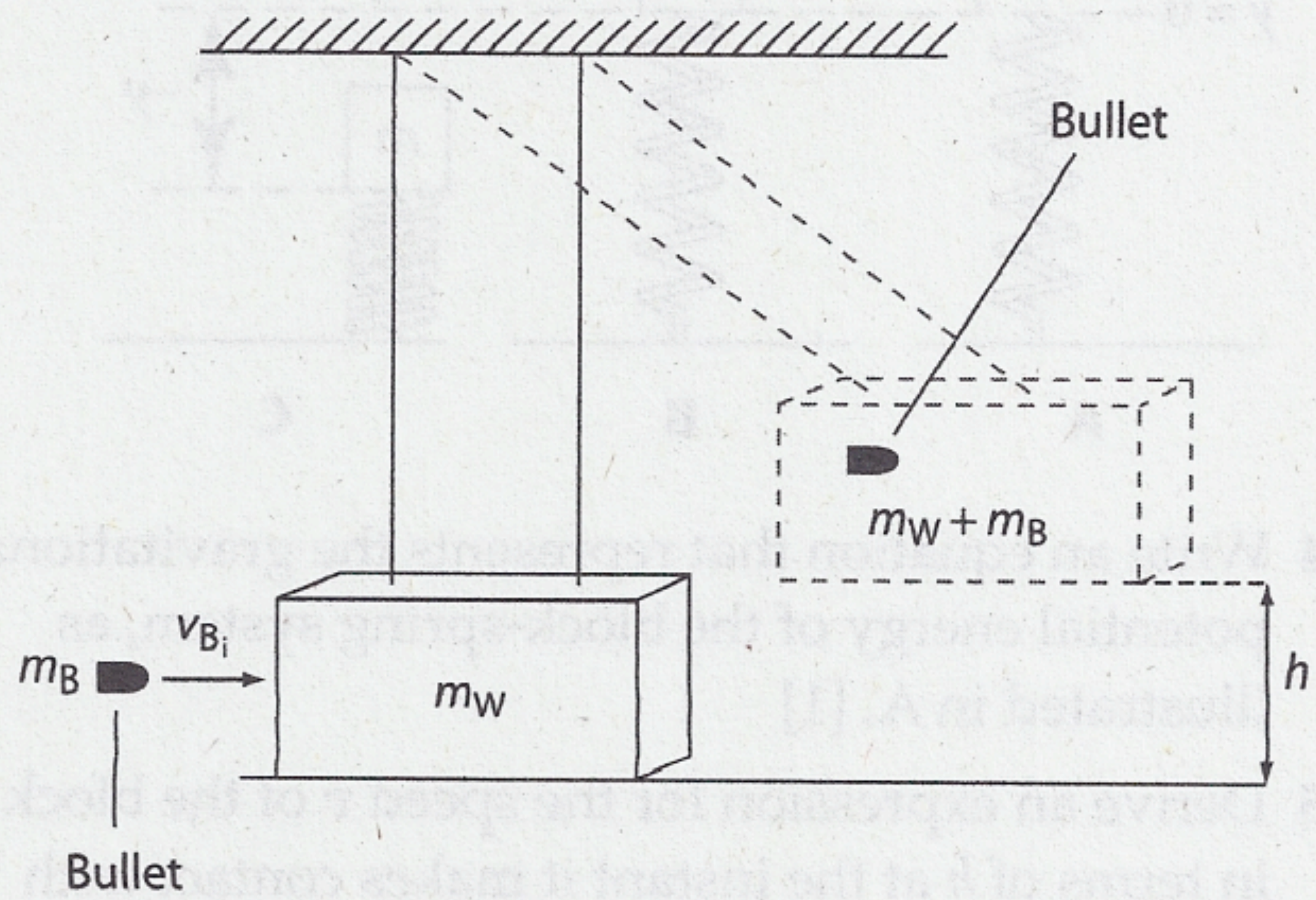
78 Determine the relationship between joules and 1.00 kilowatt · hour. [1]

79 The diagram below shows a small mass sliding along a frictionless track having a loop of radius r.



Using your knowledge of energy and circular motion, prove that if the object is to remain on the track at the top of the loop, the minimum height h from which the object must be released from rest is $\frac{5r}{2}$. [4]

80 A ballistic pendulum is a device consisting of a large block of wood having mass m_W suspended from two light-weight wires. The device is used to measure the initial speed v_{B_i} of a bullet having mass m_B. The bullet is shot into the wood and stopped. The block with embedded bullet has speed v_f immediately after the collision. As the diagram below shows, the bullet-block system swings through some vertical distance h, as mechanical energy is conserved.



Derive an expression for the vertical distance h in terms of m_w, m_B, v_B, and g. [3]

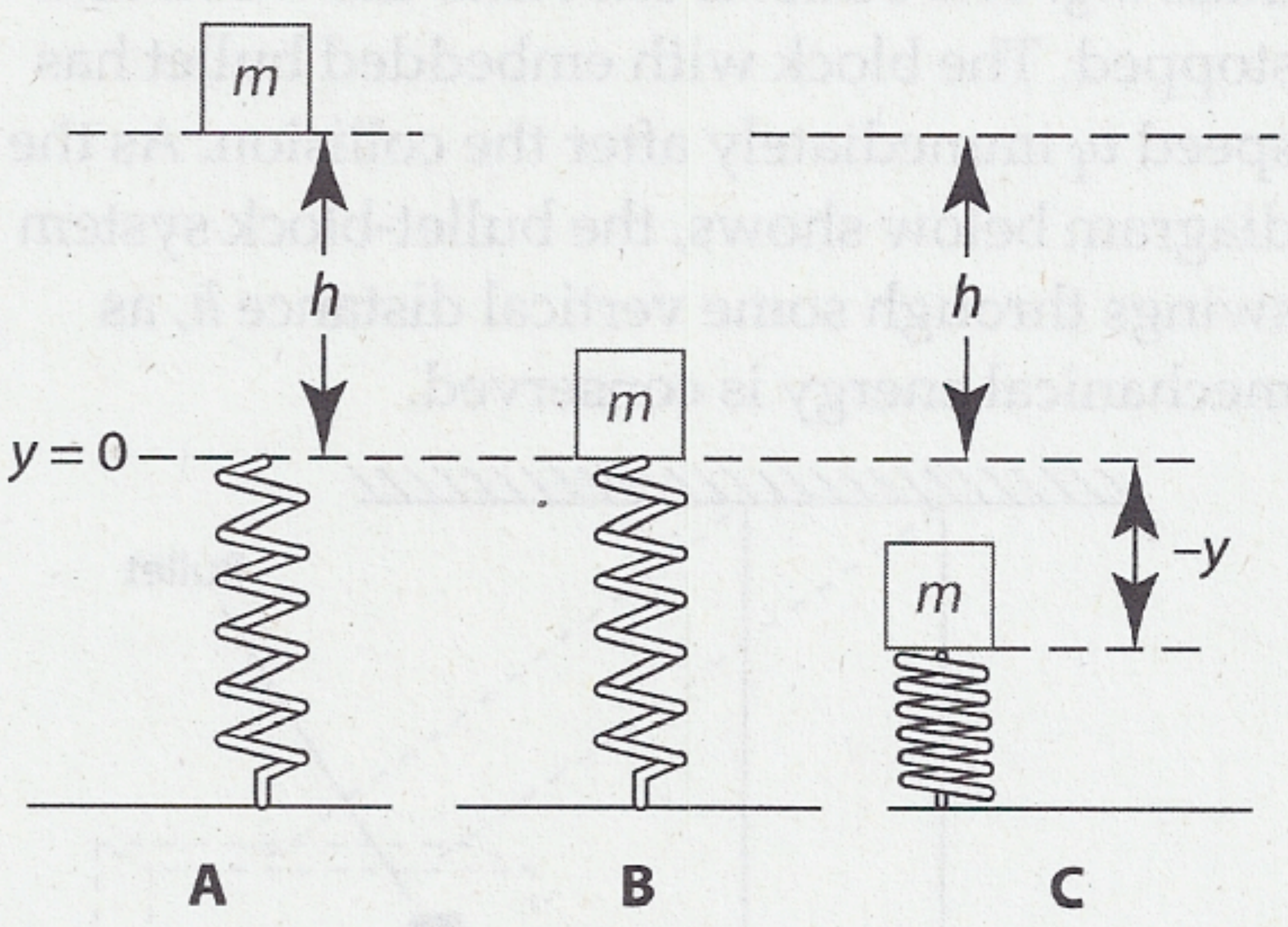
81 When a mass m, hanging from a spring with spring constant k, is set into up-and-down simple harmonic motion, it has a period of vibration T, which is given by the equation $T = 2\pi\sqrt{\frac{m}{k}}$. The amount of elastic potential energy PE_s stored in this spring at any given instant is dependent on its spring constant k and its elongation x. Derive an expression for the potential energy stored in the spring, PE_s, in terms of m, T, and x. [2]

82 A spring in a toy car is compressed a distance, x. When released, the spring returns to its original length, transferring its energy to the car. Consequently, the car having mass m moves with speed v. Derive the spring constant, k, of the car's spring in terms of m, x, and v. [Assume an ideal mechanical system with no loss of energy.] [2]

83 A cart with mass m possesses kinetic energy KE. Write an expression to represent the magnitude of the momentum p of the cart in terms of m and KE. [1]

Base your answers to questions 84 through 87 on the information and diagrams below.

A block of mass m falls from rest a vertical distance h before striking a spring and compressing it a distance $-y$. The spring has spring constant k. At the point where the block first makes contact with the uncompressed spring, the block has speed v and distance is assumed to be zero. [Assume an ideal system.]



84 Write an equation that represents the gravitational potential energy of the block-spring system, as illustrated in A. [1]

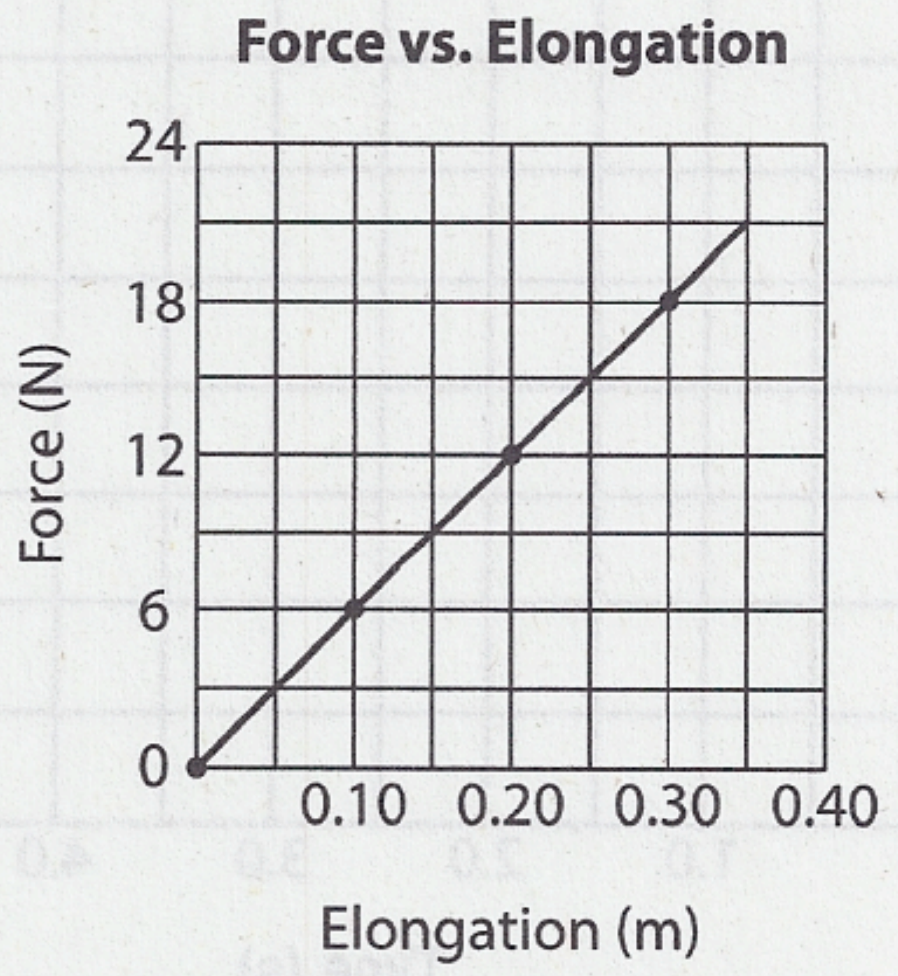
85 Derive an expression for the speed v of the block in terms of h at the instant it makes contact with the uncompressed spring. [1]

86 When the block comes to rest, the spring is compressed a distance $-y$. Write an equation that represents the conservation of energy of the block-spring system in B and C in terms of the variables stated in the problem or other conventional terms. [2]

87 Derive an expression for the spring constant k in terms of g, v, m, and y. [1]

Base your answers to questions 88 and 89 on the following information.

A student performed an experiment in which the force applied to a spring was varied and the resulting elongation measured. The data was graphed, as shown, and the spring constant of the spring was determined to be 60. newtons per meter.



The equivalent spring constant for multiple springs connected in parallel is given by the following equation:

$$k_{\text{eq parallel}} = k_1 + k_2 + k_3 + \ \ldots$$

For multiple springs connected in series the equivalent spring constant is given by the equation:

$$\frac{1}{k_{\text{eq series}}} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} + \ \ldots$$

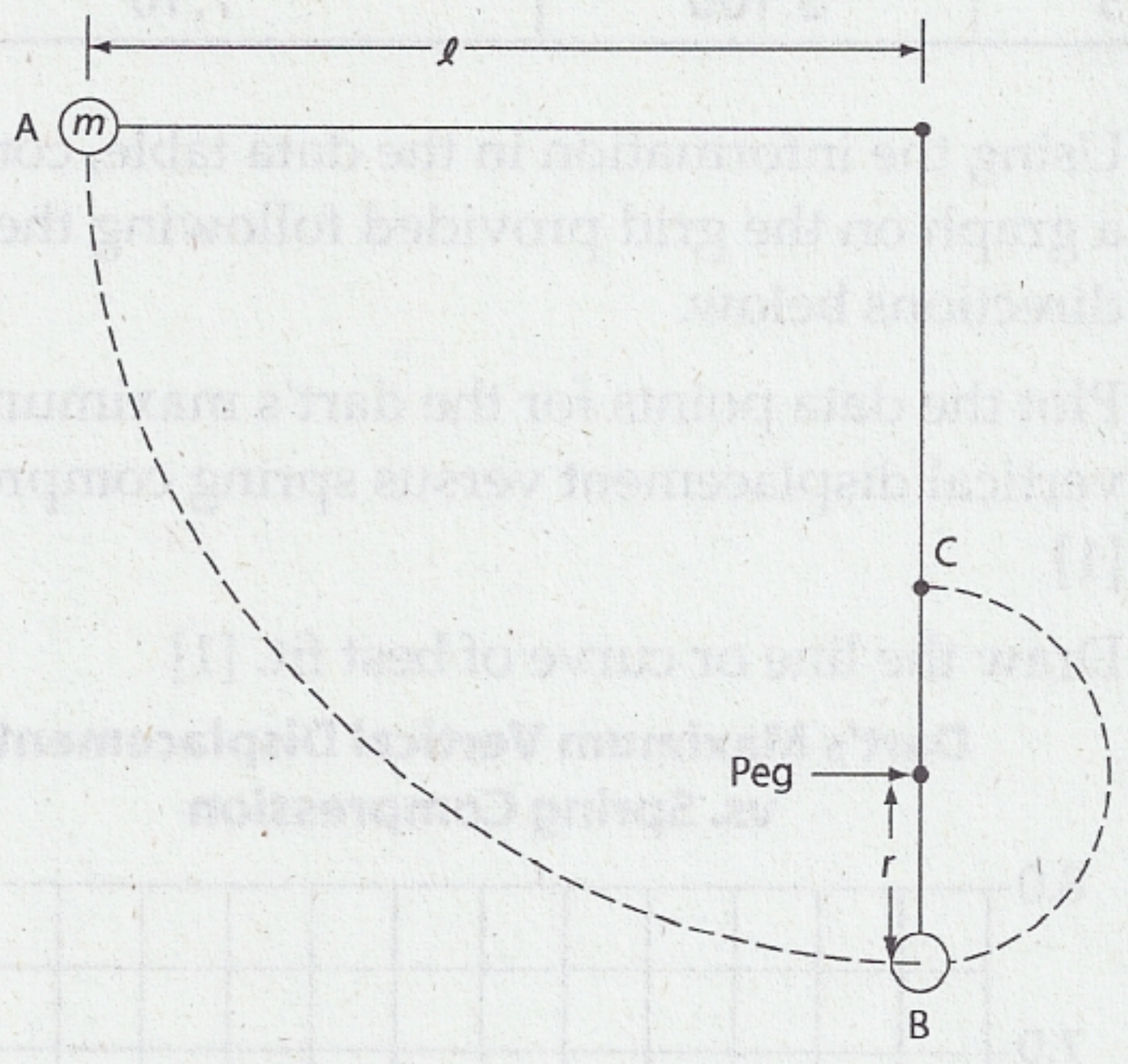
In these equations, k_1, k_2, and k_3 are the spring constants of the individual springs.

88 On a grid, draw a line to represent two identical springs with a spring constant of 60. newtons per meter connected in series. Label the line $k_{\text{eq series}}$. [1]

89 On the grid draw a line to represent the same two springs connected in parallel. Label the line $k_{\text{eq parallel}}$. [1]

Base your answers to questions 90 through 92 on the following information and diagram.

A simple pendulum of length ℓ has a bob of mass m. The bob is released from rest at point A and swings to point B directly below the pivot point. At B the cord comes in contact with a peg located a distance r above the center of the bob. This causes the bob to travel in a circular path to point C, as shown. [Neglect friction. Assume a gravitational potential energy of zero at point B.]



90 Derive an expression for the speed v_B of the bob at point B in terms of ℓ and g. [2]

91 Write an expression for the gravitational potential energy of the bob at point C. [1]

92 Derive an expression for the speed v_C of the bob at point C in terms of ℓ, r, and g. [2]

Base your answers to questions 93 through 96 on the information below.

The driver of a car made an emergency stop on a straight horizontal road. The wheels locked and the car skidded to a stop. The marks made by the rubber tires on the dry asphalt are 16 meters long, and the car's mass is 1200 kilograms.

93 Determine the weight of the car. [1]

94 Calculate the magnitude of the frictional force the road applied to the car in stopping it. [2]

95 Calculate the work done by the frictional force in stopping the car. [2]

96 Assuming that energy is conserved, calculate the speed of the car before the brakes were applied. [2]

Base your answers to questions 97 through 99 on the information below.

A 50.-kilogram child running at 6.0 meters per second jumps onto a stationary 10.-kilogram sled. The sled is on a level frictionless surface.

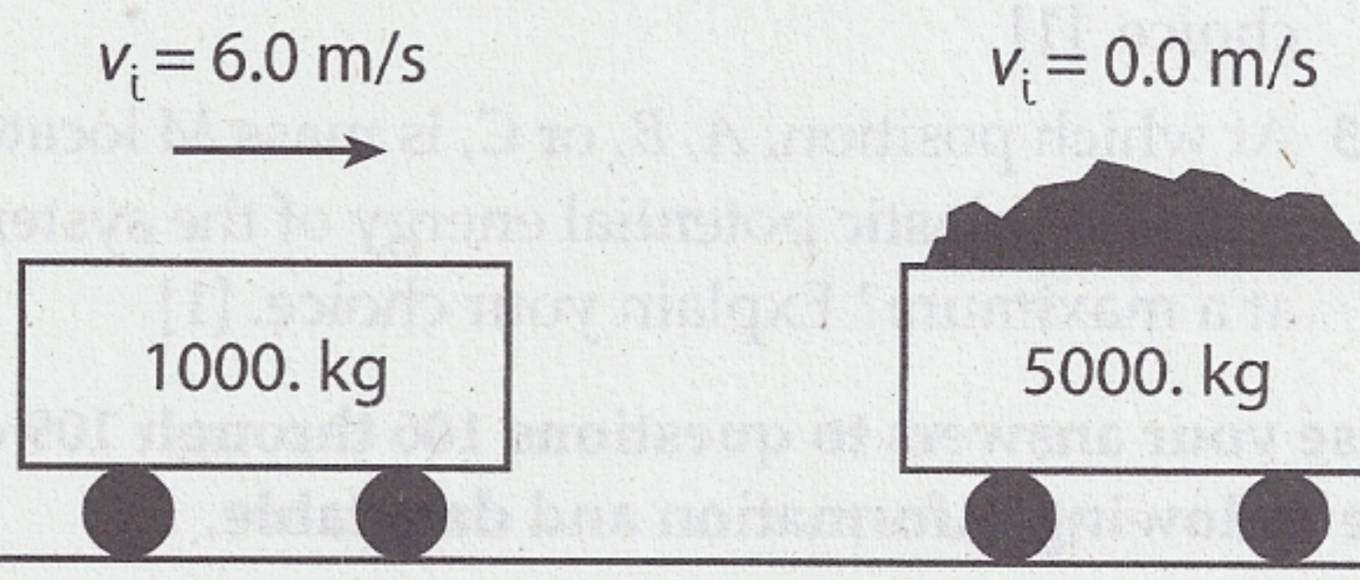
97 Calculate the speed of the sled with the child after she jumps onto the sled. [2]

98 Calculate the kinetic energy of the sled with the child after she jumps onto the sled. [2]

99 After a short time, the moving sled with the child aboard reaches a rough level surface that exerts a constant frictional force of 54 newtons on the sled. How much work must be done by friction to bring the sled with the child to a stop? [1]

Base your answers to questions 100 through 102 on the information and diagram below.

A 1000.-kilogram empty cart moving with a speed of 6.0 meters per second is about to collide with a stationary loaded cart having a total mass of 5000. kilograms, as shown. After the collision, the carts lock and move together. [Assume friction is negligible.]



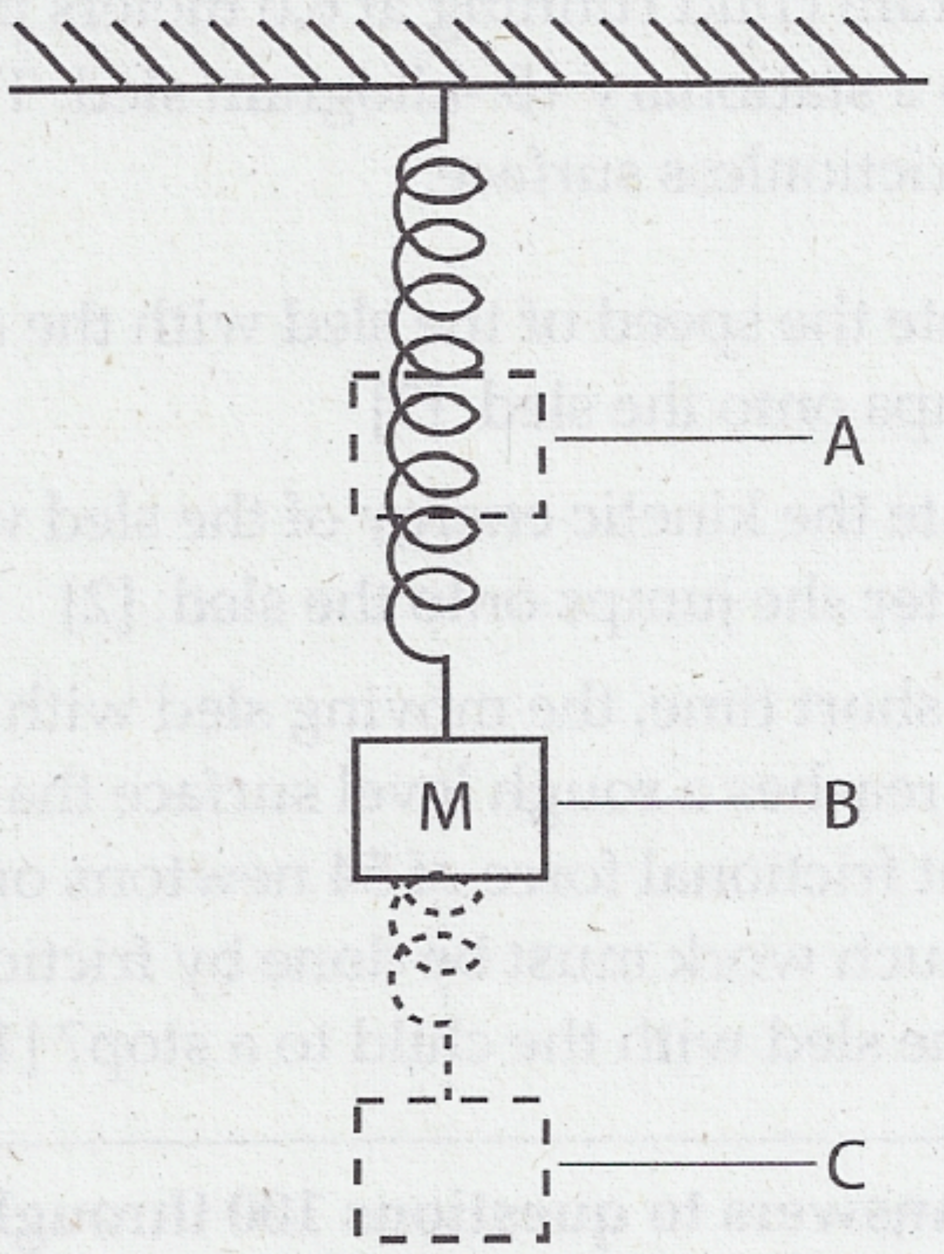
100 Calculate the speed of the combined carts after the collision. [2]

101 Calculate the kinetic energy of the combined carts after the collision. [2]

102 How does the kinetic energy of the combined carts after the collision compare to the kinetic energy of the carts before the collision? [1]

Base your answers to questions 103 through 105 on the information and diagram below.

A mass, *M*, is hung from a spring and reaches equilibrium at position *B*. The mass is then raised to position *A* and released. The mass oscillates between positions *A* and *C*. [Neglect friction.]



103 At which position, *A*, *B*, or *C*, is mass *M* located when the kinetic energy of the system is at a maximum? Explain your choice. [1]

104 At which position, *A*, *B*, or *C*, is mass *M* located when the gravitational potential energy of the system is at a maximum? Explain your choice. [1]

105 At which position, *A*, *B*, or *C*, is mass *M* located when the elastic potential energy of the system is at a maximum? Explain your choice. [1]

Base your answers to questions 106 through 109 on the following information and data table.

The spring in a dart launcher has a spring constant of 140 newtons per meter. The launcher has six power settings, 0 through 5, with each successive setting having a spring compression 0.020 meter beyond the previous setting. During testing, the launcher is aligned to the vertical, the spring is compressed, and a dart is fired upward. The maximum vertical displacement of the dart in each test trial is measured. The results of the testing are shown in the table.

Data Table

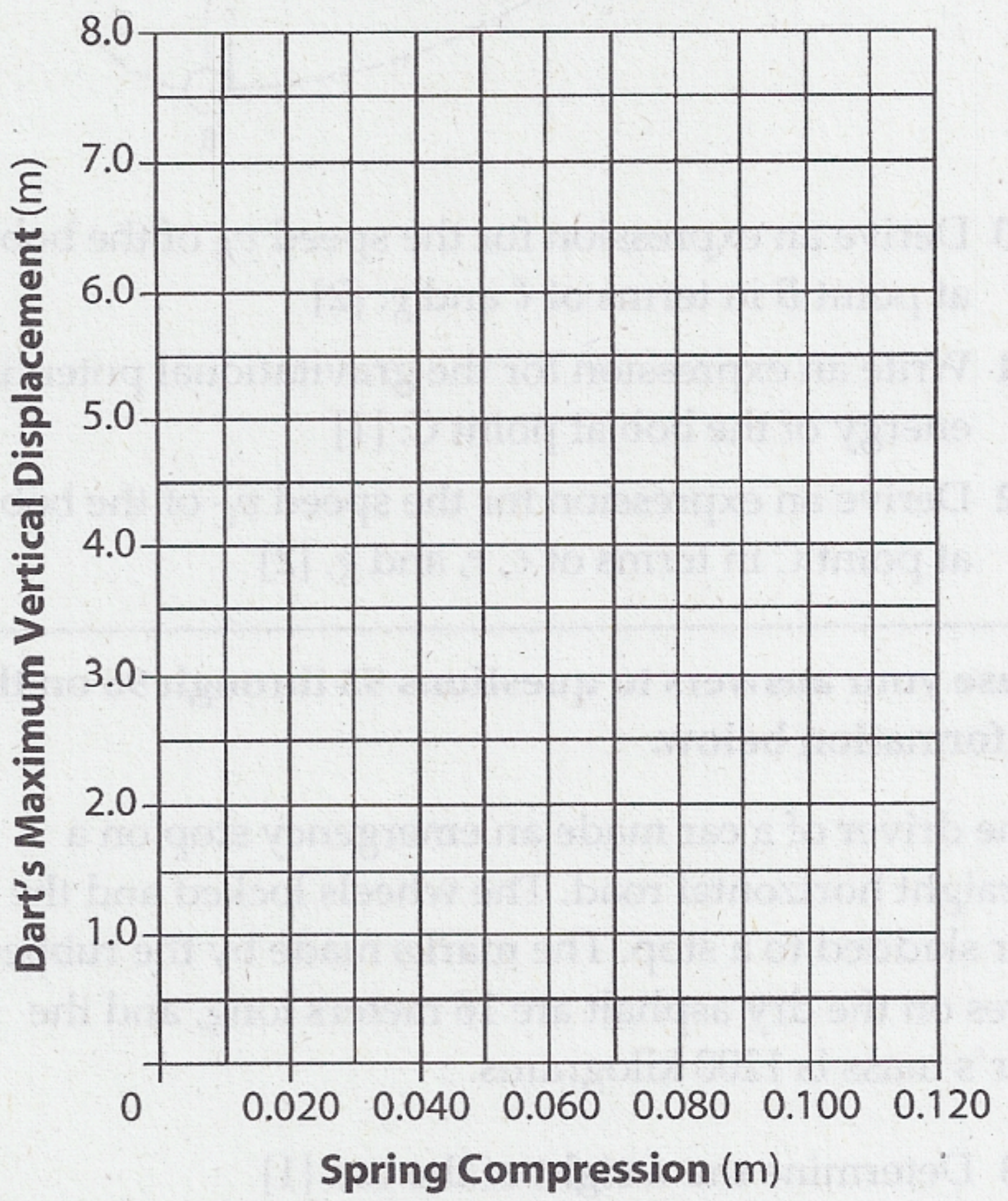
Power Setting	Spring Compression (m)	Dart's Maximum Vertical Displacement (m)
0	0.000	0.00
1	0.020	0.29
2	0.040	1.14
3	0.060	2.57
4	0.080	4.57
5	0.100	7.10

Using the information in the data table, construct a graph on the grid provided following the directions below.

106 Plot the data points for the dart's maximum vertical displacement versus spring compression. [1]

107 Draw the line or curve of best fit. [1]

Dart's Maximum Vertical Displacement vs. Spring Compression



108 Using information from your graph, calculate the energy provided by the compressed spring that causes the dart to achieve a maximum vertical displacement of 3.50 meters. [2]

109 Determine the magnitude of the force, in newtons, needed to compress the spring 0.040 meter. [1]