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.

$$\Delta PE = mg\Delta h$$

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

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

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

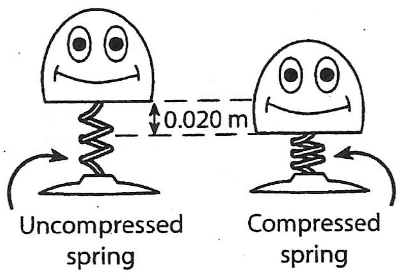
51. A force of 0.2 newton is needed to compress a spring a distance of 0.02 meter. The potential energy stored in this compressed spring is

(1) 8×10^{-5} J (3) 2×10^{-5} J
(2) 2×10^{-3} 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 (3) 4 J
(2) 8.0 J (4) 4.0 J

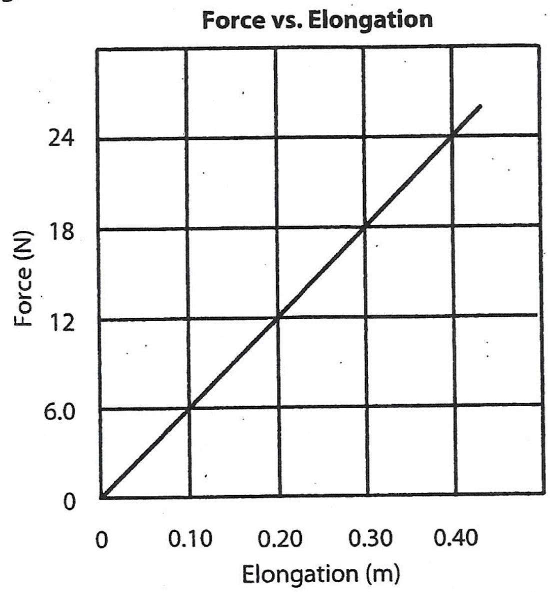
53. In the diagram below, a child compresses the spring in a pop-up toy 0.020 meter.



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 (3) 3.4 J
(2) 0.14 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 (3) 9.8 J
(2) 6.0 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.

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

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

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

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

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?

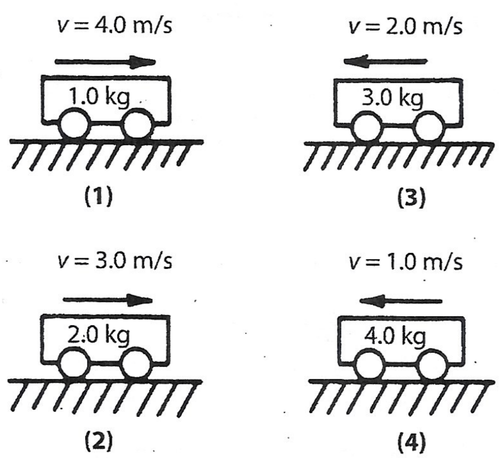
(1) 1.6×10^3 J
(2) 2.0×10^4 J
(3) 8.0×10^3 J
(4) 4.0×10^3 J

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.

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
(2) 2 J
(3) 50 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:

$$F_s = kx$$ Ⓡ

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.

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

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.)