TOPIC 3

Energy

Vocabulary

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

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.

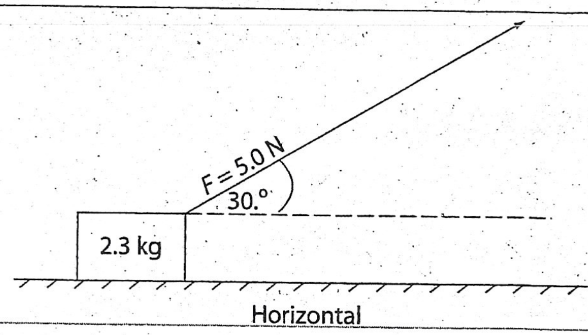
$$1 \text{ newton} \cdot \text{meter} = (1 \text{ kilogram} \cdot \text{meter/second}^2)(\text{meter})$$
$$1 \text{ newton} \cdot \text{meter} = 1 \text{ kilogram} \cdot \text{meter}^2/\text{second}^2 = 1 \text{ joule}$$

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 trigonometic 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:

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

Ⓡ

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

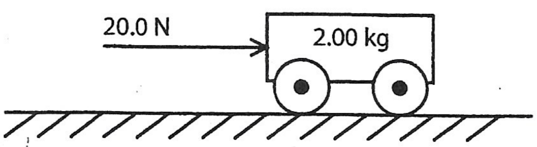
2. A jack exerts a vertical force of 4.5×10^3 newtons to raise a car 0.25 meter. How much work is done by the jack?
   (1) 5.6×10^{-5} J
   (2) 1.1×10^3 J
   (3) 4.5×10^3 J
   (4) 1.8×10^4 J

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.

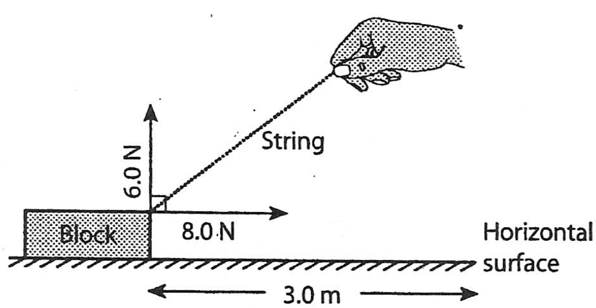
7. A constant force with a magnitude of 1.9×10^3 newtons is required to keep an automobile having a mass of 1.0×10^3 kilograms moving at a constant speed of 20. meters per second. The work done in moving the automobile a distance of 2.0×10^3 meters is
   (1) 2.0×10^4 J
   (2) 3.8×10^4 J
   (3) 2.0×10^6 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
   (2) 500. J
   (3) 700. 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.