CHAPTER 6

Energy is transferred and transformed by forces doing work.

Learning Expectations

By the end of this chapter, you will:

Relating Science to Technology, Society, and the Environment

- analyze the transfer and transformation of energy in a hydro power station, a wind turbine, and a fuel cell

Developing Skills of Investigation and Communication

- solve problems relating to work, force, and displacement
- use the law of conservation of energy to solve problems involving work, gravitational potential energy, and kinetic energy
- plan and conduct inquiries involving transformations between gravitational potential energy and kinetic energy
- solve problems involving the relationship between energy, work, time, and power
- compare and contrast the input energy, useful output energy, and percent efficiency of selected energy generation methods

Understanding Basic Concepts

- describe and explain energy transfers and transformations
- relate energy, work, and power, and describe their related units
- explain kinetic energy, gravitational potential energy, power, and efficiency, and identify their related units
- describe the conditions that are required for work to be done

You pedal slowly up the hill, transforming chemical energy from food into the energy of motion. Slowly, you pull over the top of the hill. Your energy has now largely become energy of position. Then you are freewheeling effortlessly down the hill, pulled by gravity, and again, you have the energy of motion (Figure 6.1). Near the bottom of the hill, you begin to apply the brakes. Friction converts the bicycle's energy of motion into thermal energy in the brake pads. The bike slows to a stop.

Energy is one of the most fundamental concepts in physics. Everything that occurs in nature can be traced back to energy. It explains the behaviour of systems large and small, from the cosmic to the subatomic. Energy connects everything together, from mechanics to heat, acoustics, optics, and electromagnetism. Every technology involves energy transfers and transformations, and every society needs an understanding of energy to function.

Figure 6.1 The force of gravity pulls the cyclist down the hill.

6.1 Work and Conservation of Energy

Section Summary

- There are many forms of energy.
- Energy can be transformed from one form to another, and transferred from one object to another.
- When work is done, energy is transferred.
- Work is done when a force acts over a distance.
- The mechanical energy of a system is the sum of the kinetic energy and the potential energy in the system.
- Energy cannot be created or destroyed.

Energy is the ability to do work. Whenever anything happens, anywhere in the universe, energy is involved.

Energy exists in many different forms (Table 6.1). **Kinetic energy** is the energy possessed by an object due to its motion. A thrown ball, a speeding bicycle, and a falling rock all have kinetic energy. **Potential energy** is energy stored in matter due to its position or the arrangement of its parts. A stretched spring, an object raised to a height above Earth's surface, atoms and molecules, and electric charges all possess potential energy.

Table 6.1 Common Forms of Energy

Form	Description
Radiant energy	the energy of electromagnetic waves
Kinetic energy	the energy possessed by an object due to its motion
Potential energy	energy stored in matter due to its position or the arrangement of its parts
Gravitational potential energy	the potential energy associated with the gravitational field
Elastic potential energy	the potential energy stored in an object when it is temporarily forced out of shape
Chemical potential energy	the potential energy stored in chemical bonds
Nuclear potential energy	the potential energy stored in the nucleus of an atom
Electrical potential energy	the potential energy associated with electric charges
Thermal energy	the energy associated with the movement and interactions of the particles in an object (the total kinetic and potential energy of an object's particles)
Sound energy	the energy in sound waves

Energy Transformations

Any form of energy can be transferred from one place to another, or transformed from one form to another. Whenever anything happens, energy is transferred or transformed. But because energy cannot be created or destroyed, the total amount of energy in the system remains the same.

An archer pulls back her bowstring (Figure 6.2). Chemical potential energy in her muscles is transformed into elastic potential energy in the bow. Energy has been transferred from her muscles to the bow. When the archer releases the string, the bow and the string push on the arrow. The elastic potential energy of the bow is transformed, in part, into the kinetic energy of the arrow.

A ski lift carries a skier up a slope. The lift's motor turns a wheel that circulates a cable, which carries chairs up and down the lift. The chemical potential energy of the motor's fuel is transformed into gravitational potential energy of the skier. Energy has been transferred from the fuel to the skier. Then, as the force of gravity pulls the skier downhill (Figure 6.3), gravitational potential energy is transformed into kinetic energy.

Figure 6.2 Work is done when the elastic potential energy of the bow is transformed into the kinetic energy of the moving arrow, string, and bow.

Figure 6.3 The skier gained gravitational potential energy as he rode up the ski lift. During the downhill run, this gravitational potential energy is converted into kinetic energy.

Calculating Work

In the examples above, one or more forces do work. In everyday life, we think of work as any task that requires significant physical or mental effort. But in physics, work has a more specific meaning. **Work** is done when a force acts over a distance. The result is a transfer of energy from one object to another and from one form to another. Energy is the ability to do work.

Look again at the archer in Figure 6.2. She pulls the string and the string moves parallel to the applied force. When a force acts on an object in the direction of motion of the object, then the work, W, done by the force is the product of the force, F, and the distance moved, Δd.

$$W = F\Delta d$$

Any type of force — gravity, applied, friction, tension, and so on — can do work.

The magnitude of a force is measured in newtons, and the distance over which the force acts is measured in metres. If a force acts in the direction of the motion, work is the product of force and distance, so the unit of work is the **newton metre (N·m).** A newton metre is called a **joule (J),** after British physicist James Prescott Joule (1818–1889).

$1\ \text{N·m} = 1\ \text{J}$

When you calculate the work done by a force, you are measuring the amount of energy transferred. The joule is also the unit of energy.

A joule is a very small unit. It takes one joule of energy to lift a small apple one metre above the ground. Larger units of work and energy are the **kilojoule (kJ),** megajoule (MJ), and gigajoule (GJ).

$1\ \text{kJ} = 1 \times 10^3\ \text{J} \qquad 1\ \text{MJ} = 1 \times 10^6\ \text{J} \qquad 1\ \text{GJ} = 1 \times 10^9\ \text{J}$

Work and energy are scalar quantities: they do not depend on direction. The archer in Figure 6.2 knows from experience how much force to apply to the string to move it the appropriate distance. If she pulls the string toward her, the string moves toward her. If she pulls the string to the right, it moves right. In both cases, work is done. The work done is the combined effect of the force and distance. In general, as long as the force acts in the direction of motion, work is done.

Concept Check

1. Explain the difference between kinetic and potential energy.
2. What is the relationship between work and energy?
3. Show that $1\ \text{J} = 1\ \dfrac{\text{kg·m}^2}{\text{s}^2}$.

Example 6.1

A mother pushes a stroller along the sidewalk, as shown in Figure 6.4. She exerts a horizontal force of 123 N as the stroller moves 42.5 m. Calculate the work done.

Given

$F = 123\ \text{N}$

$\Delta d = 42.5\ \text{m}$

Required

work (W)

Analysis and Solution

$$\begin{aligned} W &= F\Delta d \\ &= (123\ \text{N})(42.5\ \text{m}) \\ &= 5227.5\ \text{N·m} \\ &= 5227.5\ \text{J} \\ &= 5.23\ \text{kJ} \end{aligned}$$

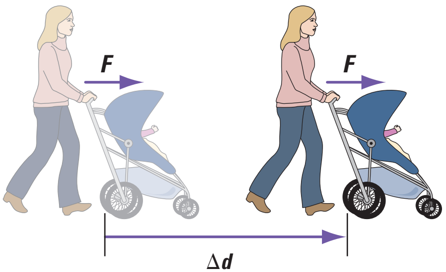


Figure 6.4

Paraphrase

The mother does 5.23 kJ of work while pushing the stroller.

Practice Problems

1. How much work will you do if you push a full recycling bin 33.5 m along a sidewalk using a horizontal force of 175 N?
2. How much work does a child do pulling a loaded wagon with a horizontal force of 316 N for 25.2 m?
3. You do 45.8 J of work when you lift a bag of potatoes 0.752 m straight up using a vertical force. Find the magnitude of this applied force.

Answers

1. 5.86 kJ
2. 7.96 kJ
3. 60.9 N

The formula for work, $W = F\Delta d$, is used when a force acts in the direction of motion of an object. This is an idealized situation. Let's look at a slightly more realistic scenario. Consider the boy pushing the box in Figure 6.5. Because of his height, the boy pushes both forward and down. But the box moves horizontally. Only the horizontal part of the applied force contributes to the motion of the box. It is called the component of the force parallel to the motion. Only the horizontal component of the applied force does work. The formula for this is $W = (F\cos\theta)\Delta d$.

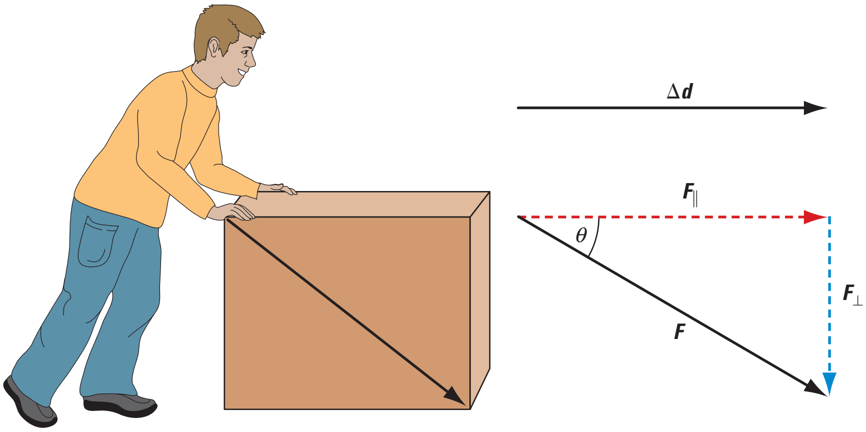


Figure 6.5 When a force F acts on an object and the object moves a distance Δd, only the component of the force that acts parallel to the direction of motion does work. If the box moves horizontally, only the horizontal component, $F_{\parallel}$, does work.

There is another complication with the boy and the box. There are several forces involved in this situation in addition to the force applied by the boy. Gravity pulls down on the box, the normal force of the floor pushes up on the box, and friction acts in the direction opposite to the motion. If several forces act on an object, each force may do work on the object. Each force may transfer energy to or from the object.

When Is Work Done?

When you push against a wall, the wall does not move. No work is done on the wall. When you stand holding a heavy book, you exert a force on the book to hold it up, but the position of the book does not change, so no work is done on the book.

If a spacecraft is drifting through deep space at constant speed, there is no force of any kind acting on the spacecraft. No work is done because no energy is transferred. If a skier reaches a smooth, horizontal stretch of snow and glides for a while at a constant speed (neglecting friction), there is motion, but no applied force. No work is done in this situation, either.

For work to be done, there must be a force and motion, but these alone are not enough. Part of the force must act in the same direction as the movement. As shown in Figure 6.5, you can think of a force as having two parts or components — one parallel to the direction of motion and one perpendicular to the direction of motion. Only when there is a component of the force that is parallel to the direction of the motion is work done.

Thus, for work to be done:

1. A force must act on the object.
2. The object must change position.
3. There must be a component of the force parallel to the direction of the motion.

Concept Check

1. Describe a situation in which work is done and explain why work is done.
2. Explain why no work is done in each of these situations.
   (a) A puck slides across level ice at constant speed (neglecting friction).
   (b) A person carries a cup of coffee across the kitchen.
   (c) A person holds up a flag for an hour.
3. Describe another situation in which no work is done, and explain why.

Positive and Negative Work

A soccer ball rests on the field. You are the goalkeeper, and your team has been awarded a goal kick. You run up and kick the ball down the field. You do work on the ball: your foot exerts an applied force and remains in contact with the ball over a distance, and the ball moves in the direction of the kick. Your foot causes the ball to speed up. Energy is transferred from you *to* the ball (Figure 6.6(a)).

A player gives the ball a high kick toward the goal. You use your hands and arms to stop the ball: you apply an opposing force over a distance. You do work on the ball, and energy is transferred *from* the ball to you (Figure 6.6(b)).

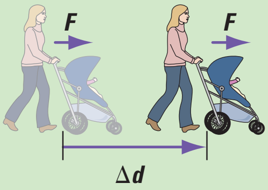
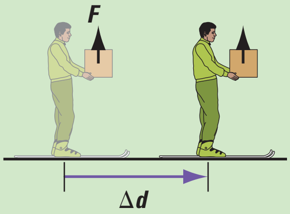
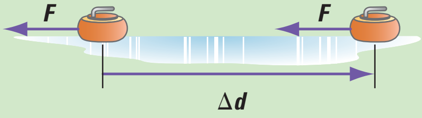
When a force acts in the direction of motion of an object, the work done is **positive**, and energy is transferred *to* the object. When a force acts in the direction opposite to an object's motion, energy is transferred *from* the object and the work done is **negative**, so in this case,

$$W = -F\Delta d$$

Table 6.2 on the next page summarizes the work done when the directions of force and motion are parallel, perpendicular, and anti-parallel (in exactly opposite directions).

Figure 6.6 (a) When the goalkeeper kicks the ball, he will transfer energy to the ball. (b) When the goalkeeper stops the ball, energy will be transferred from the ball to him.

Table 6.2 Positive Work, Negative Work, and No Work

	Positive Work ($W > 0$) 	**No Work ($W = 0$)** 	**Negative Work ($W < 0$)** 
Type of force	applied force	applied force	force of friction
Direction of force	to the right	up	to the left
Direction of motion	to the right	to the right	to the right
Force and motion are ...	parallel	perpendicular	anti-parallel
Work done	The applied force does work on the stroller.	No work is done on the box.	The force of friction does work on the curling stone.
Result	The stroller speeds up.	The box moves at constant speed.	The curling stone slows down.

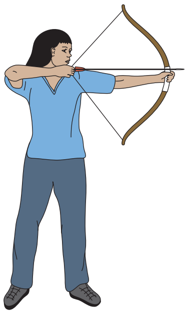


Figure 6.7 The arrow gains kinetic energy as it accelerates.

Concept Check

1. Describe the transfer of energy in each of the three situations shown in Table 6.2.
2. A van bumps into the car ahead and the van's air bag inflates. The air bag does work on the driver of the van. Is the work positive or negative? Explain.
3. A dog on a leash pulls a child along a sidewalk. The dog, through the leash, does work on the child. Is the work positive or negative? Explain.

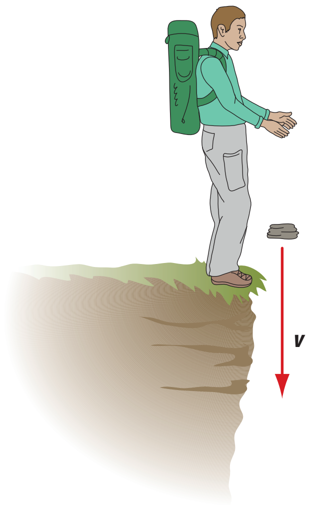


Figure 6.8 When an object is in free fall, the force of gravity does work to increase the object's kinetic energy.

Kinetic Energy

When the archer in Figure 6.7 releases the arrow, the bowstring exerts a force on the arrow that accelerates the arrow toward the target. As the arrow gains speed, it gains kinetic energy. Kinetic energy (E_k) is the energy due to the motion of an object. When the hiker in Figure 6.8 drops the rock off the cliff, the force of gravity accelerates the rock downward, increasing its speed and thus its kinetic energy.

The kinetic energy of an object with mass m and moving at speed v is represented by

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

As the formula shows, the kinetic energy of a moving object is directly proportional to the object's mass and to the square of the speed at which the object is moving. An object with a large mass has more kinetic energy than an object with a small mass moving at the same speed. An object moving twice as fast as another will have four times as much kinetic energy, even though the objects have the same mass.

Example 6.2

(a) A large curling stone (mass 20 kg) slides along the ice at 2.0 m/s. What is the kinetic energy of this stone?
(b) What is the speed of a small curling stone (mass 10 kg) with the same kinetic energy as the large curling stone?

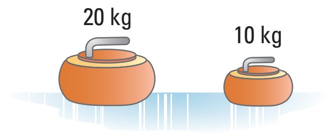


Figure 6.9

Given

(a) $m_L = 20\text{ kg}$
$v_L = 2.0\text{ m/s}$
(b) $m_S = 10\text{ kg}$
$E_{k_S} = E_{k_L}$

Required

(a) kinetic energy of large stone (E_{k_L})
(b) speed of small stone (v_S)

Analysis and Solution

(a) Find E_{k_L} by using $E_k = \frac{1}{2}m(v)^2$.

$$\begin{aligned} E_{k_L} &= \frac{1}{2}m_L(v_L)^2 \\ &= \frac{1}{2}(20\text{ kg})\left(2.0\ \frac{\text{m}}{\text{s}}\right)^2 \\ &= 40\ \frac{\text{kg}\cdot\text{m}^2}{\text{s}^2} \\ &= 40\text{ J} \end{aligned}$$

(b) Use $E_{k_S} = E_{k_L}$ to find the speed of the small stone.

$$\begin{aligned} E_{k_S} &= \frac{1}{2}m_S(v_S)^2 \\ 40\text{ J} &= \frac{1}{2}(10\text{ kg})(v_S)^2 \\ 2(40\text{ J}) &= (10\text{ kg})(v_S)^2 \\ \frac{2(40\text{ J})}{10\text{ kg}} &= (v_S)^2 \\ v_S &= \sqrt{\frac{80\text{ J}}{10\text{ kg}}} \\ &= \sqrt{8.0\ \frac{\text{m}^2}{\text{s}^2}} \\ &= 2.8\text{ m/s} \end{aligned}$$

Paraphrase

(a) The kinetic energy of the large curling stone is 40 J.
(b) The small curling stone is moving at 2.8 m/s.
Notice that the speed is not double that of the large stone.

Practice Problems

1. A 45.6-kg girl pedals a 16.4-kg bicycle at a speed of 2.51 m/s. What is the kinetic energy of the girl and bike together?
2. A car travelling at 79.3 km/h on a highway has 4.22×10^5 J of kinetic energy. What is the mass of the car?
3. A skateboarder with a mass of 65.0 kg increases his speed from 1.75 m/s to 4.20 m/s as he rolls down a ramp. What is the increase in his kinetic energy?

Answers

1. 195 J
2. 1.74×10^3 kg
3. 474 J

Concept Check

1 Show that the units for $\frac{1}{2}mv^2$ simplify to joules.

2. Suppose the speed of a car increases by a factor of three. By what factor does its kinetic energy increase?

3. In which of the following situations does the kinetic energy increase more? Explain.
   - A bicycle accelerates from 0 m/s to 1 m/s.
   - The same bicycle accelerates from 10 m/s to 11 m/s.

Kinetic Energy and Work

Newton's second law states that when an unbalanced force acts on an object, the object will accelerate in the direction of the unbalanced, or net, force. The larger the net force, the greater the acceleration. A larger force also means that more work is done and the kinetic energy of the object changes more.

The concept of work leads to an alternate statement of Newton's second law. The work done by an unbalanced force in moving an object is equal to the change in the kinetic energy of the object (final kinetic energy − initial kinetic energy):

$$\begin{aligned} W &= E_{k_f} - E_{k_i} \\ &= \Delta E_k \end{aligned}$$

Let's test this equation in a simple situation: a weightlifter drops a 50.0-kg bar from a height of 1.50 m (Figure 6.10). The force of gravity, $F_g = mg$, is the only force involved, and the distance the bar moves is 1.50 m. So, the equation $W = F\Delta d$ can be used to find the work done by gravity. Both the force of gravity and the direction of motion are downward, so the work done will be positive.

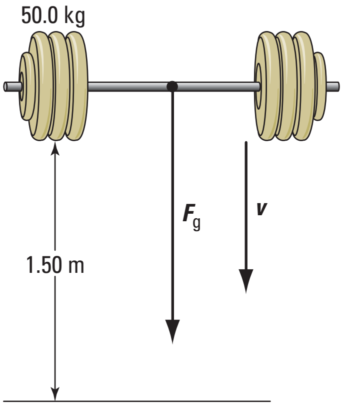


Figure 6.10

$$\begin{aligned} F_g &= mg \\ &= (50.0\ \text{kg})\left(9.81\ \frac{\text{m}}{\text{s}^2}\right) \\ &= 490.5\ \text{N} \end{aligned}$$

$$\begin{aligned} W &= F\Delta d \\ &= (490.5\ \text{N})(1.50\ \text{m}) \\ &= 735.75\ \text{J, or } 736\ \text{J} \end{aligned}$$

The work done, W, is 736 J.

Next, calculate the change in kinetic energy, $\Delta E_k = E_{k_f} - E_{k_i}$. Since the bar is initially at rest, its initial kinetic energy is 0 J. The bar's final kinetic energy can be found using $E_k = \frac{1}{2}m(v)^2$. But first, the final speed, v_f, must be found.

To find v_f, you can use the fifth equation of motion: $(v_f)^2 = (v_i)^2 + 2a\Delta d$, which was introduced in Unit A. The bar starts from rest and accelerates at 9.81 m/s² for a distance of 1.50 m, so the values of a and v_i are known. The bar falls from a height of 1.50 m to the floor, so $\Delta d = 1.50$ m.

Calculate the final speed:

$$\begin{aligned} (v_f)^2 &= (v_i)^2 + 2a\Delta d \\ &= \left(0\ \frac{\text{m}}{\text{s}}\right)^2 + 2\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)(1.50\ \text{m}) \\ &= 29.43\ \frac{\text{m}^2}{\text{s}^2} \\ v_f &= 5.4249\ \text{m/s} \end{aligned}$$

PHYSICS INSIGHT

Motion problems that do not involve time can often be solved using energy. Look over the problems in this section. They are similar to ones in Units A and B. None of them contain time. Work or energy is used to find the answer.

Now, calculate the final kinetic energy.

$$\begin{aligned} E_{k_f} &= \frac{1}{2}m_f(v_f)^2 \\ &= \frac{1}{2}(50.0\ \text{kg})\left(5.4249\ \frac{\text{m}}{\text{s}}\right)^2 \\ &= 736\ \text{J} \end{aligned}$$

Calculate the change in kinetic energy.

$$\begin{aligned} \Delta E_k &= E_{k_f} - E_{k_i} \\ &= 736\ \text{J} - 0\ \text{J} \\ &= 736\ \text{J} \end{aligned}$$

As the force of gravity pulls the bar toward the floor, it does 736 J of work. As the bar speeds up, it gains 736 J of kinetic energy.

Braking Forces

A fighter jet returning to an aircraft carrier faces a very short runway. The braking mechanism is a hook on the bottom of the plane and a series of cables strung across the runway on the deck. As the plane comes in, the hook catches a cable (Figure 6.11). The plane and hook pull the cable forward a bit while the cable tightens and slows the plane.

The force of the cable is the net force on the plane. Since the work done by the cable on the plane is negative, the relation $W = \Delta E_k$ says that the change in kinetic energy of the plane should be negative. And it is — the plane slows down. Kinetic energy is transferred *from* the plane to the cable, and eventually to the aircraft carrier.

Figure 6.11 When the jet's tailhook catches the cable, kinetic energy is transferred from the jet, slowing it down.

Many different forces can play the role of a braking force. The fighter jet slows because the cable provides an opposing force. A curling stone sliding along the ice slows because the force of friction acts in the opposite direction to the motion. Modern trains have electromagnets mounted on the rails to produce an opposing magnetic force.

Example 6.3

A roller-coaster train moving at 8.15 m/s glides to rest over 19.2 m along the final horizontal stretch of track. The mass of the train is 1490 kg, and the train stops because its brakes apply an opposing force. Use work and kinetic energy to determine the braking force.

Given

$v_i = 8.15$ m/s

$v_f = 0$ m/s

$m = 1490$ kg

$\Delta d = 19.2$ m

Required

braking force (F)

Analysis and Solution

Use $E_k = \frac{1}{2}m(v)^2$. The final kinetic energy of the train is 0 J, because its final speed is 0 m/s. So, calculate the initial kinetic energy of the train and the change in kinetic energy.

$$\begin{aligned} E_{k_i} &= \frac{1}{2}m_i(v_i)^2 \\ &= \frac{1}{2}(1490\ \text{kg})\left(8.15\ \frac{\text{m}}{\text{s}}\right)^2 \\ &= 4.948 \times 10^4\ \text{J} \end{aligned}$$

$$\begin{aligned} \Delta E_k &= E_{k_f} - E_{k_i} \\ &= 0\ \text{J} - (4.948 \times 10^4\ \text{J}) \\ &= -4.948 \times 10^4\ \text{J} \end{aligned}$$

The change in kinetic energy is also the work done by the braking force.

$$\begin{aligned} W &= \Delta E_k \\ &= -4.948 \times 10^4\ \text{J} \end{aligned}$$

Now, use the definition of work to find the force.

$$\begin{aligned} W &= -F\Delta d \\ -4.948 \times 10^4\ \text{J} &= -F(19.2\ \text{m}) \\ F &= \frac{4.948 \times 10^4\ \text{J}}{19.2\ \text{m}} \\ &= 2577.1\ \frac{\text{kg}\cdot\text{m}}{\text{s}^2} \\ &= 2577.1\ \text{N} \\ &= 2.58 \times 10^3\ \text{N} \end{aligned}$$

Paraphrase

The kinetic energy of the train decreases because the train is slowing. The work done by the braking force is negative: the brakes are transferring energy from the train as thermal energy (heat). The braking force has a magnitude of 2.58×10^3 N and acts to oppose the motion.

Practice Problems

Use work and kinetic energy to solve these problems.

1. A 1250-kg car accelerates from rest to 6.13 m/s over a distance of 8.58 m. Calculate the average force of traction.
2. You toss a 52.1-g ball straight up. The ball leaves your hand at 7.53 m/s. How high above your hand does the ball go? Hint: The force of gravity does work.
3. A skater pushes on the back of a 45.3-kg sled with an average force of 72.5 N over a distance of 15.6 m. Find the final speed of the sled if it was moving at 1.31 m/s initially.

Answers

1. 2.74×10^3 N
2. 2.89 m
3. 7.19 m/s

Concept Check

1. You push a child in a wagon forward with a horizontal force, running faster and faster to keep up. Is the change in kinetic energy of the child and wagon positive or negative? Justify your answer in at least two ways.
2. A car is moving forward at 20 km/h when the driver applies the brakes. Is the change in kinetic energy of the car positive or negative? Justify your answer in at least two ways.
3. Two strong people push a refrigerator across a rough stretch of floor at constant speed (Figure 6.12).
   (a) Is the work done by the applied force positive or negative?
   (b) Is the work done by friction positive or negative?
   (c) Is the work done by the net force positive or negative?
   (d) What is the change in kinetic energy of the fridge?

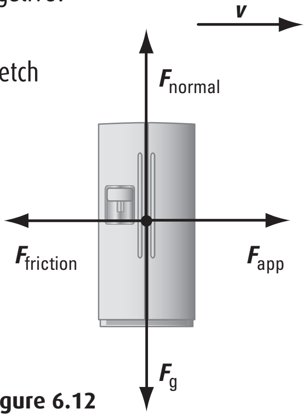


Figure 6.12

Gravitational Potential Energy

An object has potential energy if it has the ability to do work because of its position or the arrangement of its parts. There are several forms of potential energy, including chemical, elastic, electrical, and gravitational potential energy. **Gravitational potential energy (E_g)** is the energy possessed by an object due to its height. A rock on the edge of a cliff has the ability to do work because it could crush something if it fell — it has gravitational potential energy.

PHYSICS•SOURCE

Suggested Activity

- C1 Quick Lab Overview on page182

Rather than climb dozens of flights of stairs, the passengers in the elevator shown in Figure 6.13 are lifted vertically by the elevator mechanism. If we ignore friction, the lifting force is equal in magnitude to the force of gravity, $F_g = mg$, where m is the mass and g is the acceleration due to gravity (approximately 9.81 m/s^2). The work done by the machinery to lift the passengers and elevator from the ground to a height h is

$$\begin{aligned} W &= F_g \Delta d \\ &= (mg)h \end{aligned}$$

This is the gravitational potential energy, E_g, of the elevator and passengers at height h. So, the gravitational potential energy of an object of mass m at a height h above the ground is

$$E_g = mgh$$

The height, h, is always measured from a level of reference considered to have a potential energy value of zero. Usually, this level is the lowest position the object can attain — Earth's surface, or ground or floor level — in the given situation.

The equation $E_g = mgh$ shows that an object's height relative to the chosen reference level, its mass, and the acceleration due to gravity all affect its gravitational potential energy. A backpack has less gravitational potential energy when it is on the floor than on a desk, and more when a big textbook is added to its contents. The backpack would have less gravitational potential energy if it were on the same desk on the surface of Mars, because the force of gravity on Mars is much less than the force of gravity on Earth.

Figure 6.13 The elevator's motor does work, lifting the elevator and its passengers to the observation tower. The higher the elevator and passengers rise, the more gravitational potential energy they gain.

Example 6.4

The drop-tower gondola and its passengers in Figure 6.14 have a combined mass of 500.0 kg. What is the change in their gravitational potential energy when they are lifted 48.0 m up from the base of the tower?

Given

$m = 500.0$ kg

$h_i = 0$ m

$h_f = 48.0$ m

Required

change in gravitational potential energy (ΔE_g)

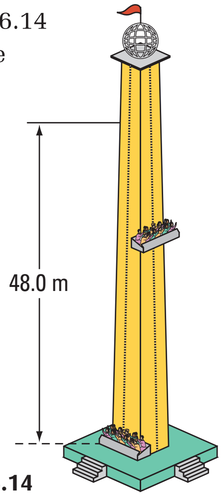


Figure 6.14

PHYSICS INSIGHT

The gravitational potential energy of an object depends only on its vertical height, because no work is done against gravity to move an object horizontally.

Analysis and Solution

Solve for the initial and final gravitational potential energies, and then find the change in gravitational potential energy.

$$\begin{aligned} E_{\mathrm{g_i}} &= mgh_{\mathrm{i}} \\ &= (500.0\ \mathrm{kg})\left(9.81\ \frac{\mathrm{m}}{\mathrm{s}^2}\right)(0\ \mathrm{m}) \\ &= 0\ \mathrm{J} \end{aligned}$$

$$\begin{aligned} E_{\mathrm{g_f}} &= mgh_{\mathrm{f}} \\ &= (500.0\ \mathrm{kg})\left(9.81\ \frac{\mathrm{m}}{\mathrm{s}^2}\right)(48.0\ \mathrm{m}) \\ &= 2.3544 \times 10^5\ \mathrm{J} \end{aligned}$$

$$\begin{aligned} \Delta E_{\mathrm{g}} &= E_{\mathrm{g_f}} - E_{\mathrm{g_i}} \\ &= (2.3544 \times 10^5\ \mathrm{J}) - 0\ \mathrm{J} \\ &= 2.3544 \times 10^5\ \mathrm{J} \\ &= 235\ \mathrm{kJ} \end{aligned}$$

Paraphrase

The change in gravitational potential energy of the gondola and passengers is +235 kJ. The gondola and passengers were pulled upward, gaining gravitational potential energy.

Practice Problems

1. A book with a mass of 1.45 kg gains 25.0 J of potential energy when it is lifted from the floor to a shelf. How high above the floor is the shelf?
2. A pile driver drops a mass of 550 kg from a height of 12.5 m above the ground onto the top of a pile that is 2.30 m above the ground. How much gravitational potential energy is released during the drop?
3. A roller-coaster train begins its journey 5.25 m above the ground. As the motor tows the train to the top of the first hill, it gains 4.20×10^5 J of gravitational potential energy. If the combined mass of the train and its passengers is 875 kg, how far above the ground is the top of the hill?

Answers

1. 1.76 m
2. 55.0 kJ released
3. 54.2 m

Choosing a Reference Level

The reference level that is chosen for measuring the height of an object affects the initial and final values of potential energy in a calculation, but not the change in potential energy.

Sometimes it is not obvious where you should put the reference level. Lake Huron is 176 m above sea level and Lake Superior is 183 m above sea level (Figure 6.15). To find the change in potential energy of a lake freighter as it passes from Lake Huron to Lake Superior, you could use sea level as $h = 0$ m. Another choice would be to use Lake Huron as $h = 0$ m. Each option has its advantages. Since both options give the same answer, you can use either reference level, as shown in the next example.

Figure 6.15 A lock raises and lowers boats between stretches of water of different levels. The Soo Locks at Sault Ste. Marie connect Lake Huron to the higher Lake Superior.

Example 6.5

A lake freighter with a gross mass of 35 000 t travels from Lake Huron to Lake Superior through the Soo Locks. Find the change in the freighter's gravitational potential energy using the following as the level of reference:

(a) sea level (b) Lake Huron

Given

m = 35 000 t

elevation of Lake Huron = 176 m

elevation of Lake Superior = 183 m

Required

change in gravitational potential energy (ΔE_g)

Analysis and Solution

Table 6.3 Two Choices of Reference Level

Reference Level	Sea Level	Lake Huron
Initial height	$h_i = 176\ \text{m}$	$h_i = 0\ \text{m}$
Final height	$h_f = 183\ \text{m}$	$h_f = (183 - 176)\ \text{m} = 7\ \text{m}$
Mass	$m = 35\ 000\ \text{t} \times \dfrac{1000\ \text{kg}}{1\ \text{t}}$ $= 3.5 \times 10^7\ \text{kg}$	
Initial gravitational potential energy	$E_{g_i} = mgh_i$ $= (3.5 \times 10^7\ \text{kg})\left(9.81\ \dfrac{\text{m}}{\text{s}^2}\right)(176\ \text{m})$ $= 6.0430 \times 10^{10}\ \text{J}$	$E_{g_i} = mgh_i$ $= (3.5 \times 10^7\ \text{kg})\left(9.81\ \dfrac{\text{m}}{\text{s}^2}\right)(0\ \text{m})$ $= 0\ \text{J}$
Final gravitational potential energy	$E_{g_f} = mgh_f$ $= (3.5 \times 10^7\ \text{kg})\left(9.81\ \dfrac{\text{m}}{\text{s}^2}\right)(183\ \text{m})$ $= 6.2833 \times 10^{10}\ \text{J}$	$E_{g_f} = mgh_f$ $= (3.5 \times 10^7\ \text{kg})\left(9.81\ \dfrac{\text{m}}{\text{s}^2}\right)(7\ \text{m})$ $= 2.403 \times 10^9\ \text{J}$
Change in gravitational potential energy	$\Delta E_g = E_{g_f} - E_{g_i}$ $= (6.2833 \times 10^{10}\ \text{J}) - (6.0430 \times 10^{10}\ \text{J})$ $= 2.403 \times 10^9\ \text{J}$ $= 2.40\ \text{GJ}$	$\Delta E_g = E_{g_f} - E_{g_i}$ $= (2.403 \times 10^9\ \text{J}) - 0\ \text{J}$ $= 2.403 \times 10^9\ \text{J}$ $= 2.40\ \text{GJ}$

Paraphrase

The change in gravitational potential energy of the lake freighter is +2.40 GJ using either reference level.

Practice Problems

1. A 154-g ball bounces down a set of three stairs, each 17.5 cm high. Calculate the decrease in gravitational potential energy of the ball as it goes from the top step to the middle step. Use the bottom of the three stairs as the reference level.
2. Repeat question 1 using the lowest step as the reference level.
3. Repeat question 1 using the middle step as the reference level.

Answers

1. 0.264 J 2. 0.264 J 3. 0.264 J

In the problem above, using sea level as the reference level requires three calculations involving cumbersome numbers. Using Lake Huron as the reference level requires you to work out the initial and final heights, but the subsequent computations are easier.

In practical examples like the one above, the issue of significant digits is treated with some flexibility. The mass of the freighter probably has two significant digits and the lake levels three significant digits. However, when you subtract nearly equal numbers you lose significance. The change in height between Lake Huron and Lake Superior is 7 m (one significant digit). It makes sense to give the final answer here to just one or two digits.

Concept Check

1. Prove that the product of the units of m, g, and h in the formula for gravitational potential energy simplifies to joules.
2. A car is up on a lift having its oil changed. When the job is finished, the car is lowered to the ground. Describe the change in gravitational potential energy of the car.
3. You are performing a physics experiment in a room on the fourth floor of a building. Explain what you would choose as the reference level for gravitational potential energy if:
   (a) All the equipment for the experiment will stay on a table.
   (b) You are interested in a ball that bounces to the floor.
   (c) Your experiment involves dropping an object down a heating duct to the basement.

Conservation of Energy

The **law of conservation of energy** states that energy is never created or destroyed, but it can change from one form to another.

Isolated Systems

Figure 6.16 In an isolated room, the total amount of money in the room before and after a transaction is constant.

Figure 6.17 In a non-isolated room, the amount of money in the room may change.

Imagine two people in an isolated (sealed) room (Figure 6.16). They may complete as many money transfers as they like, but the total amount of money in the room before and after each transfer will be the same. The amount of money in this system is conserved — it does not change during transactions.

Now imagine that the room is not isolated. In this case, money may be taken out of (or put into) the room so that the total amount of money in the room is not necessarily constant (Figure 6.17). In this system, money is not conserved. It would be much more complex to keep track of money transfers occurring in this non-isolated room than to keep track of those occurring in the isolated room.

A **system** is a set of elements that influence one another and on which external influences act. Systems can be large (the universe) or small (an ant), and may contain many elements or as few as two. When the energy interactions of a group of objects need to be analyzed, we often assume that these objects are isolated from all other objects in the universe. Such a group is called an **isolated system**.

The law of conservation of energy can be restated as follows:

> In an isolated system, the total amount of energy never changes.

Mechanical Energy

Recall that mechanics is the field of physics concerned with the motion of objects when forces act on them. A **mechanical system** is a set of objects that interact with each other and their surroundings following the laws of motion and Newton's laws. For example, a child and a trampoline are a mechanical system.

When a child jumps up and down on a trampoline, many forms of energy and types of energy transfer and transformation are involved. There are the kinetic energy and gravitational potential energy of the child. There is **elastic potential energy** (**E_e**), the energy stored in an object — in this case the trampoline — when it is temporarily forced out of its normal shape. Chemical energy, sound energy, radiant energy, and thermal energy play a minor part as well.

Sometimes it is useful to look at just the mechanical energy in a system. **Mechanical energy** (**E_m**) is the sum of the kinetic energy, the gravitational potential energy, and the elastic potential energy of a system:

$$E_m = E_k + E_g + E_e$$

Equivalently, the mechanical energy of a system is the total of the kinetic energy and all forms of potential energy.

$$E_m = E_k + E_p$$

Consider Figure 6.18, which shows a child jumping on a trampoline at three different points in a jump. At the top of the jump, shown in part (a) of the diagram, there is no motion and the trampoline is not stretched. All of the energy is gravitational potential energy. As the child descends, some energy is transformed into kinetic energy. Just as the child touches the trampoline (b), the energy is part kinetic energy and part gravitational potential energy. As the child continues downward, stretching the trampoline, energy is transformed from kinetic energy and gravitational potential energy into elastic potential energy. At the very lowest point (c), there is still some gravitational potential energy and a lot of elastic potential energy. No matter what point in the jump the child is at, the mechanical energy of the system is the same.

For the child-trampoline system, mechanical energy is conserved. In general, if the only forces acting within or on a system are gravity and elastic forces, mechanical energy is conserved.

PHYSICS•SOURCE

Suggested Activity

- C2 Design a Lab Overview on page 182

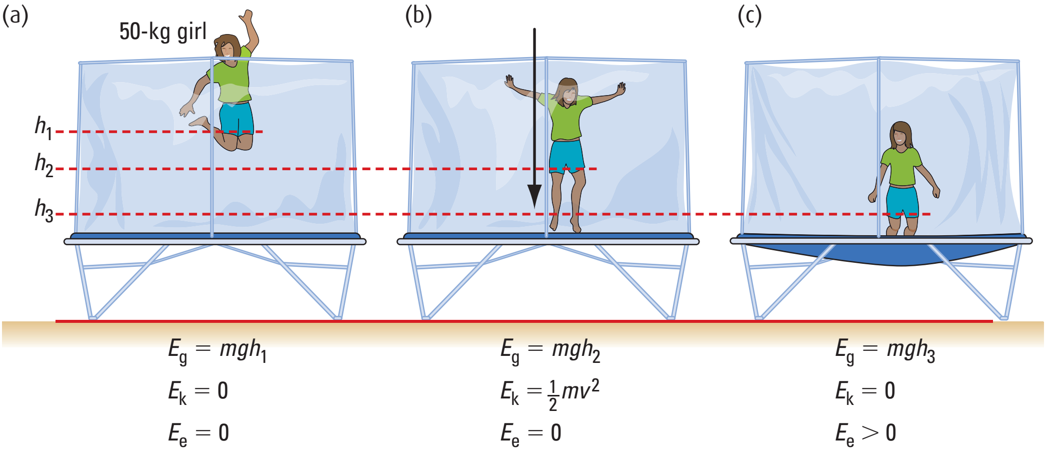


Figure 6.18 The total mechanical energy of a system is constant. The total mechanical energy of the girl and the trampoline at positions (a), (b), and (c) is the same.

Concept Check

1. What is an isolated system?
2. Which forms of energy make up mechanical energy?
3. Explain why total energy is always conserved, but the energy in a system may not be conserved.

The law of conservation of energy is often useful in solving problems where the full details of the motion are not known or needed. In Example 6.6, you don't know the exact shape of the ramp, but conservation of energy allows you to calculate the speed of the toy car at the bottom of the ramp. You don't have enough information to find how much time it takes the car to go down the ramp. In fact, ramps of different shapes will give different times. In Practice Problem 2 below, you don't know the length of the ropes on the swing or how far you pull the swing horizontally. Even with missing information, conservation of energy helps you find a speed.

Example 6.6

Figure 6.19 shows a toy-car track set up on a tabletop. The mass of the car is 25 g. Calculate the speed of the car at the bottom of the ramp, assuming friction is negligible.

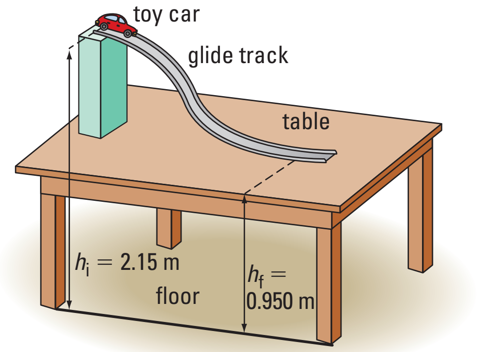


Figure 6.19

Given

$m = 25 \text{ g} = 0.025 \text{ kg}$
$h_i = 2.15 \text{ m}$
$h_f = 0.950 \text{ m}$
$v_i = 0 \text{ m/s}$

Required

final speed (v_f)

Analysis and Solution

Calculate the total energy of the system at the top of the ramp and at the bottom of the ramp.

$$\begin{aligned} E_{g_i} &= mgh_i \\ &= (0.025 \text{ kg})\left(9.81 \frac{\text{m}}{\text{s}^2}\right)(2.15 \text{ m}) \\ &= 0.5273 \text{ J} \end{aligned}$$

$$\begin{aligned} E_{k_i} &= \frac{1}{2} mv_i^2 \\ &= 0 \text{ J} \end{aligned} \qquad \begin{aligned} E_{m_i} &= E_{g_i} + E_{k_i} \\ &= 0.5273 \text{ J} \end{aligned}$$

$$\begin{aligned} E_{g_f} &= mgh_f \\ &= (0.025 \text{ kg})\left(9.81 \frac{\text{m}}{\text{s}^2}\right)(0.950 \text{ m}) \\ &= 0.2330 \text{ J} \end{aligned}$$

$$E_{k_f} = \frac{1}{2} mv_f^2 \qquad \begin{aligned} E_{m_f} &= E_{g_f} + E_{k_f} \\ &= (0.2330 \text{ J}) + \frac{1}{2} mv_f^2 \end{aligned}$$

Practice Problems

1. The toy car in Example 6.6 continues to move and rolls off the table. Find the car's speed just before it hits the floor.
2. A 14.8-kg child sits in a 1.30-kg swing. You pull the swing back, lifting it 52.1 cm vertically, and then let go. Determine the speed of the child and swing as the swing moves past its lowest point.
3. A roller-coaster train and its passengers have a combined mass of 841 kg. The train comes over the top of the first hill, 85.0 m above the ground, with a speed of 0.200 m/s. The train goes down the first hill and up to the crest of the second hill, 64.0 m above the ground. Ignore the effect of frictional forces. What is the kinetic energy of the train at the top of the second hill?

Answers

1. 6.5 m/s
2. 3.20 m/s
3. 173 kJ

Use conservation of energy. The initial and final total energies are equal.

$$
\begin{aligned}
E_{\mathrm{m_i}} &= E_{\mathrm{m_f}} \\
0.5273\ \mathrm{J} &= (0.2330\ \mathrm{J}) + \frac{1}{2} m v_{\mathrm{f}}^2 \\
0.2943\ \mathrm{J} &= \frac{1}{2}(0.025\ \mathrm{kg}) v_{\mathrm{f}}^2 \\
v_{\mathrm{f}}^2 &= \frac{2 \times 0.2943\ \mathrm{J}}{0.025\ \mathrm{kg}} \\
&= 23.544\ \frac{\mathrm{m}^2}{\mathrm{s}^2} \\
v_{\mathrm{f}} &= 4.9\ \mathrm{m/s}
\end{aligned}
$$

Paraphrase

The final speed of the car is about 4.9 m/s. The kinetic energy of the car increases while the gravitational energy of the car decreases by the same amount.

PHYSICS•SOURCE

Take It Further

Many meteors have hit Earth's surface, some causing climate change and others bringing valuable metals. It may be possible to estimate the kinetic energy of an incoming meteor from measurements of its impact crater. Scientists are testing their ideas on comets! Investigate the kinetic energy of comets and summarize your findings in a poster.

The Role of Friction

The law of conservation of energy is one of the fundamental principles of science and a powerful mathematical model for analysis and prediction of the behaviour of objects within systems.

It is often difficult if not impossible to analyze all of the many types of energy in a system. It is much easier to analyze the three types of energy that make up mechanical energy. Conservation of mechanical energy is a valuable tool for understanding motion. For example, the aerial moves of circus acrobats, high divers, and snowboarders can be analyzed as transformations of gravitational potential energy and kinetic energy. Collisions among several objects, such as a number of cars in an accident or balls in a game like billiards, can be analyzed as transformations of kinetic energy and elastic potential energy.

In reality, there is almost always friction acting. If there is, the quantity of mechanical energy in the system is not constant. For example, consider a toboggan and its passengers going downhill on rough snow and ice (Figure 6.20). This toboggan-passenger system is a mechanical system. At the top of the hill, all of the energy of this mechanical system is mechanical energy, consisting of the gravitational potential energy of the toboggan and its passengers. As the toboggan slides, friction is an opposing force transforming some energy from the toboggan into thermal energy. By the time the toboggan gets to the bottom of the hill, it is moving quite fast, but not as fast as it would have been without friction. The mechanical energy of the system at the end of the run is less than at the beginning. The "missing" energy has been transferred from the toboggan as heat. Energy is always conserved, but the mechanical energy in a system may or may not be conserved.

Figure 6.20 Friction acts to reduce the mechanical energy in a system. A toboggan sliding over a rough snowy surface will be brought to rest by the force of friction. There is no way to get back the original kinetic energy of the toboggan after friction has brought the toboggan to rest. The motion of the toboggan has been transformed into kinetic energy of the atoms that make up the toboggan and the snow.

C1 Quick Lab

Energy Changes of a Roller Coaster

Purpose

To observe how the energy of a roller-coaster train varies as it travels along a frictionless track

Activity Overview

In this Quick Lab, you will use an animation to observe how a roller-coaster train's energy is constantly changing between potential energy and kinetic energy, each of which are represented by a bar. You will use a ruler to measure the heights of the bars at various points as the train travels along the track and record your data in a table. You will analyze the data to determine the relationship between the potential and kinetic energy as the train moves along.

Your teacher will give you a copy of the full activity.

Prelab Questions

Consider the questions below before beginning this activity.

1. Which type of force pulls the train to the top of the first hill? Does this force do work? How do you know?
2. Work is done as the train accelerates down the hill. Why? What force does the work?

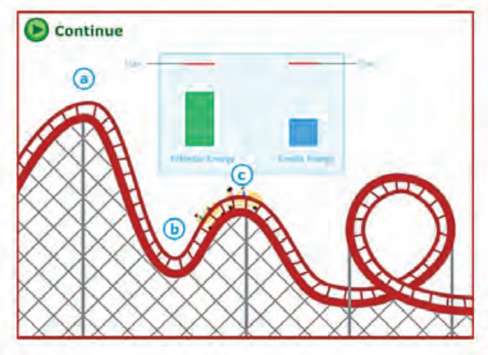


Figure 6.21 The animation stops at the top and bottom of each hill, allowing you to measure the amount of kinetic energy and potential energy at these points.

DI Key Activity

C2 Design a Lab

REQUIRED SKILLS

- Using appropriate equipment and tools
- Evaluating procedures

Energy Conservation in a Pendulum

Question

Is energy conserved during the motion of a pendulum?

Activity Overview

You will design a procedure to record the position and speed of a pendulum as it swings. A tickertape and timer, motion sensor, or photo-gates are three options for collecting data. You will analyze your data to determine the gravitational potential energy and kinetic energy of the moving pendulum at several times. You will then graph your data and analyze the graph to determine the relationship between the kinetic and potential energy of the pendulum.

Your teacher will give you a copy of the full activity.

Prelab Questions

Consider the questions below before beginning this activity.

1. What variables associated with the pendulum's motion do you need to measure its gravitational potential energy? its kinetic energy?
2. Do you know any relationships between the quantities above?

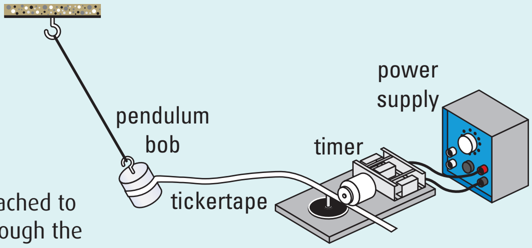


Figure 6.22 The tickertape is attached to the pendulum bob and pulled through the timer as the pendulum swings.

6.1 Check and Reflect

Key Concept Review

1. What three conditions are necessary for work to be done?

2. Describe the conditions in which a force acting over a distance will do no work.

3. Explain the relationship that exists between the kinetic energy of an object and its mass and speed.

4. Explain why a moving object has the ability to do work.

5. Explain why the work done by a braking force is negative.

6. List the form(s) of energy each object has:
(a) a sliding curling stone
(b) a book resting on a shelf
(c) a rocket during launch
(d) a mass hanging from an elastic band

7. Describe the energy transformations that occur as a diver springs up from a diving board and dives into the water below.

8. What is meant by an isolated system?

9. If energy is conserved in a system, how can work be done in the system?

Connect Your Understanding

10. A man pulls a suitcase along a rough sidewalk at constant speed.
(a) Explain why he is doing work.
(b) Why is there no increase in kinetic energy?
(c) What happens to the energy the man transfers to the suitcase?

11. A construction worker is standing on a platform suspended from the roof of a building to repair some bricks. The platform and worker have a combined mass of 355 kg. The worker raises the platform from the 5th floor, a height of 18.5 m above the sidewalk, to the 12th floor, 44.4 m above the sidewalk
(a) Calculate the change in gravitational potential energy of the worker and platform, using the sidewalk as the level of reference.
(b) Repeat part (a) using the 5th floor as the reference level.
(c) Explain why your answers in parts (a) and (b) are the same.

12. A 54.5-kg passenger in the back seat of a van is wearing a seat belt when the van runs into a stone wall. The van is originally moving at 12.6 m/s. The front end of the van collapses 0.624 m as the van comes to rest.
(a) Determine the passenger's kinetic energy before the crash.
(b) Find the average force exerted on the passenger by the seat belt.

13. A vertical force of 1510 N acts to lift a crate with a mass of 48.6 kg to a height of 24.5 m above its original position.
(a) How much work did the force do on the crate?
(b) What was the gain in the crate's gravitational potential energy?
(c) What might account for the difference in the two answers?

14. The speed of an acrobat swinging on a trapeze is 5.64 m/s at the lowest point of her motion. Assume her mass is 53.7 kg.
(a) How high above the lowest point can she swing?
(b) Do you need to know her mass to answer part (a)? Explain.

15. Choose three types of energy. Discuss how these types of energy appear in your daily life.

Reflection

16. Describe how you remember the physics concept of work. For example, do you visualize doing work yourself? Do you recall the details of a sketch of the concept? Do you think about the variables in the formula?

17. What did you learn about energy that you didn't know before you started this section?

For more questions, go to PHYSICS•SOURCE

6.2 Power

Section Summary

- Power is the rate of energy transfer.
- Machines are not perfectly efficient, because of energy losses to heat.
- Power ratings let you calculate how much energy is used in a task or activity.
- There are several sets of units commonly used to measure energy and power.

Toward the end of the 18th century, horses were the main source of energy used to drive the pumps that removed water from mines. Thus, when British inventor James Watt (1736–1819) wanted to know how his newly improved steam engine compared with existing methods of pumping water out of mines, he compared its effectiveness to that of horses. Today, we still use Watt's concept of **horsepower (hp)** to identify the power output of motors, especially in the automotive industry.

A family car with a 250-hp engine can accelerate from a standstill to 100 km/h in about 8.0 s. The power of a racing dragster's engine cannot be calculated directly, because the engine cannot be run at its top fuel output for more than 10 s at a time, but it is between 7000 and 8500 hp (Figure 6.23). This enables the dragster to accelerate from rest to speeds over 530 km/h in about 4.4 s. The dragster's engine is much more powerful than the family car's engine.

Figure 6.23 Top fuel dragsters use fuel that is up to 90 percent nitromethane, which generates more than twice the power of gasoline when combined with a given amount of oxygen. Before a drag race, each driver is allowed to perform a burnout, which heats the tires and lays down rubber at the beginning of the track, improving traction.

Recall that the amount of work done on an object, *W*, equals the change in energy of the object, ΔE. In physics, **power (*P*)** is the rate at which work is done, or the rate at which energy is transferred. The formula for power is

$$P = \frac{W}{\Delta t} \quad \text{or} \quad P = \frac{\Delta E}{\Delta t}$$

where Δt is the time taken for the work to be done or the energy to be transferred.

The greater the amount of work done or energy transferred in an amount of time, the greater the power. Compare walking up a flight of stairs to running up the stairs. The total work done or energy transferred is the same in both cases, but running requires more power than walking.

The SI unit of power is the **watt (W),** named in recognition of James Watt's contributions to physics. A power output of 1 W results when 1 J of work is done per second.

$$1\ \text{W} = \frac{1\ \text{J}}{1\ \text{s}}$$

$$= 1\ \frac{\text{J}}{\text{s}}$$

A 100-W light bulb has a power output of 100 W: it transfers energy at a rate of 100 J/s. One watt is a very small power output, so the **kilowatt (kW)** is often used to measure power:

$$1\ \text{kW} = 1000\ \text{W}$$

$$= 1\ \frac{\text{kJ}}{\text{s}}$$

Even larger units of power are the megawatt (MW) and gigawatt (GW):

$$1\ \text{MW} = 1 \times 10^3\ \text{kW} \qquad 1\ \text{GW} = 1 \times 10^6\ \text{kW}$$

PHYSICS INSIGHT

Watts and horsepower are related as follows:
1.00 hp = 746 W or about 0.75 kW

Example 6.7

An elevator and its occupants have a mass of 1300 kg (Figure 6.24). The elevator motor lifts the elevator to the 12th floor, a distance of 40.0 m, in 74.8 s. What is the average power output of the elevator motor?

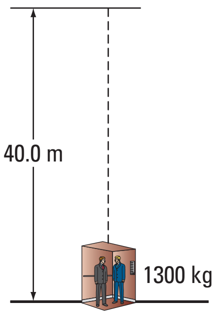


Figure 6.24

Given

$m = 1300\ \text{kg}$
$h_i = 0\ \text{m}$
$h_f = 40.0\ \text{m}$
$\Delta t = 74.8\ \text{s}$

Required

power output (P)

Analysis and Solution

The work done by the elevator's motor is equal to the gain in gravitational potential energy of the elevator and its occupants. The power output can be calculated using $P = \frac{\Delta E}{\Delta t}$. The change in gravitational potential energy can be calculated using $E_g = E_{g_f} - E_{g_i}$. The initial gravitational potential energy is 0 J because $h_i = 0$ m.

$$\begin{aligned} E_g &= E_{g_f} - E_{g_i} \\ &= (1300\ \text{kg})\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)(40.0\ \text{m}) - 0\ \text{J} \\ &= 5.1012 \times 10^5\ \text{J} \end{aligned}$$

$$\begin{aligned} P_{\text{out}} &= \frac{\Delta E_g}{\Delta t} \\ &= \frac{5.1012 \times 10^5\ \text{J}}{74.8\ \text{s}} \\ &= 6.8198 \times 10^3\ \frac{\text{J}}{\text{s}} \\ &= 6.8198 \times 10^3\ \text{W} \\ &= 6.82\ \text{kW} \end{aligned}$$

Paraphrase

The power output of the elevator's motor is 6.82 kW. The power output is equivalent to that of about sixty-eight 100-W light bulbs.

Practice Problems

1. A hair dryer produces 3.9×10^4 J of thermal energy in 30 s. Calculate its thermal power output.
2. If the power of a motor is rated at 5.60 kW, how much work can the motor do in 20.0 min? (Note: When you use the formula for P, Δt must be in seconds.)
3. A tractor pulling a plough exerts a pulling force of 7.50×10^3 N over a distance of 3.20 km. If the tractor's power output is 25.0 kW, how long does it take to do the work?

Answers

1. 1.3 kW
2. 6.72 MJ
3. 16.0 min

PHYSICS•SOURCE

Suggested Activity

- C3 Inquiry Activity Overview on page 193

Efficiency

We use many devices every day to transform energy from one form to another. Electrical potential energy is transformed by a heater into thermal energy, by a speaker into sound energy, and by a light bulb into radiant energy. If you have ever accidentally touched a light bulb when it was lit, you know that it gets very hot. Only about 5 percent of the electrical energy used by an incandescent light bulb becomes light; over 95 percent is transferred as heat (Figure 6.25).

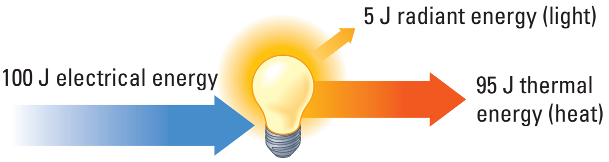


Figure 6.25 Most of the energy transformed by an incandescent light bulb is radiated as heat.

Every device wastes at least some energy by transforming it into a form that we don't want. A car's engine transforms some of the chemical potential energy in fuel into useful kinetic energy, but more than 80 percent of the chemical energy is transferred as heat and sound. The **efficiency** of a device is the ratio of useful energy or power produced, called the **output**, to the total amount of energy or power expended, called the **input**:

$$
\begin{aligned}
\textit{Efficiency} &= \frac{\text{energy output } (\Delta E_{\text{out}})}{\text{energy input } (\Delta E_{\text{in}})} \\
&= \frac{\text{power output } (P_{\text{out}})}{\text{power input } (P_{\text{in}})}
\end{aligned}
$$

Efficiency is normally calculated as a percentage.

Example 6.8

An electric motor uses 7.5×10^6 J of electrical energy to do 6.4×10^6 J of work. What is the efficiency of the motor?

Given

$\Delta E_{\text{in}} = 7.5 \times 10^6\ \text{J}$

$\Delta E_{\text{out}} = 6.4 \times 10^6\ \text{J}$

Required

efficiency of motor (*Efficiency*)

Analysis and Solution

Efficiency is the ratio of the energy output to the energy input.

$$
\begin{aligned}
\textit{Efficiency} &= \frac{\Delta E_{\text{out}}}{\Delta E_{\text{in}}} \\
&= \frac{6.4 \times 10^6\ \cancel{\text{J}}}{7.5 \times 10^6\ \cancel{\text{J}}} \\
&= 0.853
\end{aligned}
$$

Paraphrase

The efficiency of the motor is about 0.85, or 85 percent.

Practice Problems

1. A 1500-W hair dryer has a thermal power output of only 1200 W because some energy goes to moving air and making sound. Find the efficiency of the hair dryer.
2. The annual natural gas consumption for heating a small house is equivalent to 1.2×10^{11} J. The furnace has an efficiency of 85 percent. How much thermal energy is transferred to the house? How much is transferred outside?

Answers

1. 80 percent
2. 1.0×10^{11} J, 1.8×10^{10} J

The efficiency of devices that transfer energy varies widely (Table 6.4). Regular incandescent light bulbs convert only about 5 percent of the energy used into light, while the rest is emitted as heat. The efficiency of a typical compact fluorescent lamp is around 20 percent, while the efficiency of LEDs is 40 percent or more.

Devices such as laptops, cell phones, and MP3 players need to be connected to a power adapter or battery charger when their internal batteries run low. Some of these chargers have efficiencies as low as 60 percent, which means that only 60 percent of the electrical energy you pay for goes into your device. The other 40 percent is lost as heat. Newly designed chargers have 90 percent efficiency: you get 1.5 times as much usable energy from the same quantity of electrical energy.

Table 6.4 Efficiency of Some Common Devices

Device	Efficiency
Electric heater	100%
Electric motor	92%
AA battery	90%
Home gas furnace	85%
Car battery	73%
Oil furnace	66%
Automobile	14%

Concept Check

1. Rewrite 1 W in the basic SI units: kg, m, and s.
2. Why is it impossible for a device to have an efficiency greater than 100 percent?
3. What forms of energy make up the energy input for a television? What forms of energy make up the energy output? Which of the energy outputs of a television are waste energy?

Energy Consumption

A high school is a busy place for energy transformations. In the computer lab, electrical energy runs the computer hard drives, lights the computer displays, produces a variety of beeps, and moves paper across toner cartridges. Machines in the wood-working shop do work sanding and sawing, make noise, and blow air. In the kitchen, food is heated and cooled, chemical reactions take place, and mixers do work. The music lab is full of blinking lights, more computers, and much sound energy. As the day goes by, heat builds up from all these activities.

All through your community, the same story plays out: plug into a supply of energy, do something useful with it, and end up with a lot of heat (Figure 6.26).

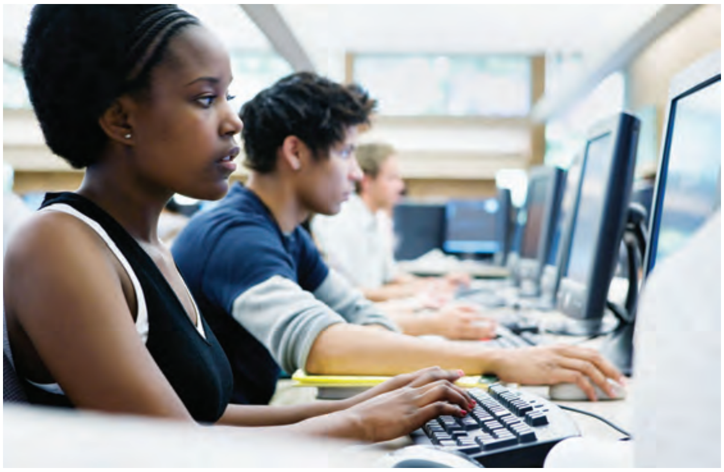


Figure 6.26 The electronics in the computer lab consume electrical energy. Most of this energy is eventually transformed into thermal energy.

Energy consumption is the conversion of produced or stored energy through useful tasks into (primarily) heat. The law of conservation of energy states that energy is not really consumed. Energy never disappears. It can, however, change from a particularly useful form into heat, which is hard to capture and control.

The energy consumed by a device is just the energy transferred to the device. If you know the input power, P, you can find the amount of energy consumed, ΔE, during a time interval Δt using the power formula:

$$P = \frac{\Delta E}{\Delta t} \quad \text{or} \quad \Delta E = P\Delta t$$

©P

Example 6.9

During a practice, a musician uses a 500-W guitar amplifier for 10 min and a 320-W keyboard amp for 30 min. How much energy is consumed?

Given

$P_{\text{guitar}} = 500 \text{ W}$ $\qquad P_{\text{keyboard}} = 320 \text{ W}$

$\Delta t_{\text{guitar}} = 10 \text{ min} = 600 \text{ s}$ $\qquad \Delta t_{\text{keyboard}} = 30 \text{ min} = 1800 \text{ s}$

Required

energy used by guitar amp (ΔE_{guitar})

energy used by keyboard amp ($\Delta E_{\text{keyboard}}$)

total energy used (ΔE_{total})

Analysis and Solution

Use the formula relating power, energy, and time, $\Delta E = P\Delta t$.

$$\begin{aligned}\Delta E_{\text{guitar}} &= P_{\text{guitar}}\,\Delta t_{\text{guitar}} \\ &= (500 \text{ W})(600 \text{ s}) \\ &= 3.00 \times 10^5 \text{ J}\end{aligned} \qquad \begin{aligned}\Delta E_{\text{keyboard}} &= P_{\text{keyboard}}\,\Delta t_{\text{keyboard}} \\ &= (320 \text{ W})(1800 \text{ s}) \\ &= 5.76 \times 10^5 \text{ J}\end{aligned}$$

$$\begin{aligned}\Delta E_{\text{total}} &= \Delta E_{\text{guitar}} + \Delta E_{\text{keyboard}} \\ &= (3.00 \times 10^5 \text{ J}) + (5.76 \times 10^5 \text{ J}) \\ &= 8.76 \times 10^5 \text{ J} \\ &= 8.8 \times 10^5 \text{ J}\end{aligned}$$

Paraphrase

The guitar amp and keyboard amp together consume about 8.8×10^5 J of energy during the practice. This amount of energy is equivalent to the amount needed to keep a 60-W light bulb burning for about 4 h.

Practice Problems

1. Calculate the energy consumed by a computer (150 W) that is used for 2.0 h and a laser printer (250 W) that is used for 10 min.
2. Calculate the energy consumed making breakfast for one: oatmeal (microwave, 1000 W, 2.0 min), toast (toaster, 1400 W, 1.0 min), and fruit smoothie (blender, 385 W, 1.0 min).
3. A cell-phone charger rated at 5.0 W has an efficiency of 60 percent. If it takes 90 min to charge the phone, how much energy is transferred to the phone? How much energy is waste energy?

Answers

1. 1.2 MJ
2. 2.3×10^5 J
3. 1.6×10^4 J, 1.1×10^4 J

Energy Consumption in Physical Activity

The swimmer in Figure 6.27 is doing work. She is pushing water backward to propel herself forward. The meal she consumed before the race provides energy to her muscles for this task and also to her lungs and circulatory system to enable them to function more quickly. The work done against the drag of the water gives both the swimmer and the water kinetic energy.

PHYSICS•SOURCE

Suggested Activity

- C4 Inquiry Activity Overview on page 193

PHYSICS•SOURCE

Explore More

How efficient are our bodies at turning food calories into the energy of an activity? Do you really burn what you eat?

Figure 6.27 Many energy transformations occur during physical activity. Different activities consume energy at different rates.

Human activity, just like the operation of machines, consumes energy. Chemical potential energy, in the form of food or body reserves, is used to perform tasks and ends up as (mostly) heat.

The amount of energy consumed during any activity depends on the power rating of the activity and the time spent on the activity (Table 6.5). Climbing stairs uses about 685 J/s (685 W), while sleeping uses about 83 J/s (83 W). Cycling at 15 km/h requires about 400 W of power (Figure 6.28), compared to 265 W for walking at 5 km/h.

Table 6.5 Power Rating for Some Human Activities

Activity	Power (W)
Playing basketball	800
Playing tennis	440
Walking (5 km/h)	265
Sitting studying	210
Sitting at rest	120
Sleeping	83

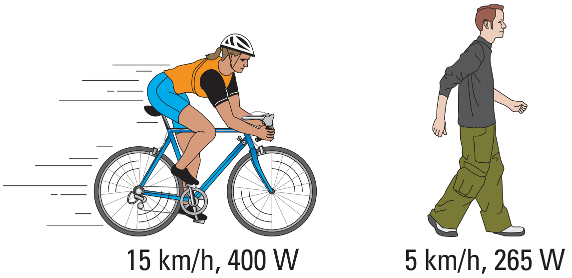


Figure 6.28 Bicycling is more energy-efficient than walking. The cyclist needs just 50 percent more power to travel at 300 percent of the walker's speed.

Physiologists, dieticians, and professionals in other health-related fields usually measure energy in kilocalories, or food calories. One **kilocalorie (kcal)** is the amount of heat required to raise the temperature of 1 kg of pure water by 1°C: 1 kcal = 4.187 kJ. A large apple provides an energy input of about 100 kcal.

Example 6.10

Compare the amount of energy consumed by playing basketball for 20.0 min and by sitting studying for 20.0 min. Use the power ratings given in Table 6.5. Give answers in both kilocalories and kilojoules.

Given

$P_B = 800$ W
$P_S = 210$ W
$\Delta t = 20.0 \text{ min} = 1200 \text{ s}$

Required

energy consumed playing basketball (ΔE_B)
energy consumed sitting studying (ΔE_S)

Analysis and Solution

Use the formula relating power, energy, and time, $\Delta E = P\Delta t$.

$$\begin{aligned}\Delta E_B &= P_B \Delta t_B \\ &= (800 \text{ W})(1200 \text{ s}) \\ &= 9.60 \times 10^5 \text{ J} \\ &= 960 \text{ kJ} \\ &= (960 \cancel{\text{kJ}})\left(\frac{1 \text{ kcal}}{4.187 \cancel{\text{kJ}}}\right) \\ &= 229 \text{ kcal}\end{aligned}$$

$$\begin{aligned}\Delta E_S &= P_S \Delta t_S \\ &= (210 \text{ W})(1200 \text{ s}) \\ &= 2.52 \times 10^5 \text{ J} \\ &= 252 \text{ kJ} \\ &= (252 \cancel{\text{kJ}})\left(\frac{1 \text{ kcal}}{4.187 \cancel{\text{kJ}}}\right) \\ &= 60.2 \text{ kcal}\end{aligned}$$

Paraphrase

In 20 min, about 960 kJ of energy is consumed by playing basketball and about 250 kJ by sitting studying. Equivalently, about 230 kcal and about 60 kcal of energy are consumed, respectively.

Practice Problems

1. How much energy is consumed in walking for 30.0 min? Use the power rating in Table 6.5. Give the answer in both kilocalories and kilojoules.
2. The game of Ultimate Frisbee consumes about 300 kcal/h. Convert this power into watts.
3. The energy consumption for walking up stairs is 0.1287 kcal/min/(kg of body mass). Calculate the power, in watts, of a 75.0-kg person climbing stairs.

Answers

1. 477 kJ or 114 kcal
2. about 350 W
3. 674 W

Concept Check

1. Does consumption of energy violate the law of conservation of energy? Explain.
2. Explain why your power while walking should depend on your walking speed.
3. You climb the CN Tower as part of a fundraising event. Your efficiency is the ratio of input energy to output energy. Describe how you might measure or calculate these two amounts of energy.

Alternative Units for Energy

The joule is the SI unit used to measure energy. A joule per second, or watt, is used to measure power. The **kilowatt hour (kW·h)** is a larger unit of energy used by electric utilities to measure energy consumption.

$$1\ \text{kW·h} = 3.6 \times 10^6\ \text{J}$$

Table 6.6 summarizes the correspondences between the two sets of energy and power units.

Table 6.6 Two Sets of Units for Energy and Power

Quality	SI Unit	Commonly Used Units
Energy, ΔE	joule (J)	kilowatt hour (kW·h) $\Delta E = P\Delta t \rightarrow 1\ \text{kW·h} = (1\ \text{kW})(1\ \text{h})$
Time, t	second (s)	hour (h)
Power, P	watt (W) $P = \frac{\Delta E}{\Delta t} \rightarrow 1\ \text{W} = \frac{1\ \text{J}}{1\ \text{s}}$	kilowatt (kW)

Electricity meters measure the amount of electrical energy used, in kilowatt hours. The monthly electricity bill for a small apartment might read "Usage: 217.42 kW·h." The quantity of electrical energy consumed can be calculated as:

$$\begin{aligned}\Delta E &= (217.42\ \cancel{\text{kW·h}})\left(\frac{3.6 \times 10^6\ \text{J}}{1\ \cancel{\text{kW·h}}}\right)\\ &= 7.8271 \times 10^8\ \text{J}\end{aligned}$$

To measure larger amounts of electrical energy used by industrial customers or by a city or region, megawatt hours (1 MW·h = 1 × 10³ kW·h), gigawatt hours (1 GW·h = 1 × 10⁶ kW·h), and even terawatt hours (1 TW·h = 1 × 10⁹ kW·h) may be used. In a year, Ontario consumes more than 150 TW·h of energy.

Appliance manufacturers worldwide give the power ratings for appliances in watts, so the amount of energy used by an appliance is expressed in kilowatt hours. Suppose you run a 1-kW microwave oven continuously for 1 h. You convert 3.6×10^6 J or 1 kW·h of electrical potential energy into heat, light, and sound:

$$\begin{aligned}\Delta E &= P\Delta t\\ &= (1000\ \text{W})(3600\ \text{s})\\ &= 3.6 \times 10^6\ \text{J}\end{aligned} \qquad \begin{aligned}\Delta E &= P\Delta t\\ &= (1\ \text{kW})(1\ \text{h})\\ &= 1\ \text{kW·h}\end{aligned}$$

Example 6.11

An old 17-cubic-foot (480 L) frost-free refrigerator uses 450 W when it is running. Assume the refrigerator runs 5.0 h each day.

(a) Determine the amount of energy consumed in a day of use, in joules and in kilowatt hours.

(b) Determine the annual energy consumption in kilowatt hours.

Given

$P = 450\ \text{W}$ $\qquad\qquad$ $\Delta t = 5.0\ \text{h}$

Required

(a) energy consumed in a day (ΔE in J and kW·h)

(b) annual energy consumption (ΔE in J and kW·h)

Analysis and Solution

(a) The problem can be done using J, s, and W or using kW·h, h, and kW. Use $\Delta E = P\Delta t$, as shown below.

Table 6.7 Two Approaches to Solution

SI Unit	Commonly Used Units
Convert Δt into seconds. $\Delta t = 5.0\ \text{h} \times \frac{3600\ \text{s}}{1\ \text{h}}$ $= 18\ 000\ \text{s}$ Calculate ΔE. $\Delta E = P\Delta t$ $= (450\ \text{W})(18\ 000\ \text{s})$ $= 8.10 \times 10^6\ \text{J}$ $= (8.10 \times 10^6\ \cancel{\text{J}})\left(\frac{1\ \text{kW·h}}{3.6 \times 10^6\ \cancel{\text{J}}}\right)$ $= 2.25\ \text{kW·h}$ $= 2.3\ \text{kW·h}$	Convert P into kW. $P = 450\ \text{W} \times \frac{1\ \text{kW}}{1000\ \text{W}}$ $= 0.450\ \text{kW}$ Calculate ΔE. $\Delta E = P\Delta t$ $= (0.450\ \text{kW})(5.0\ \text{h})$ $= 2.25\ \text{kW·h}$ $= (2.25\ \cancel{\text{kW·h}})\left(\frac{3.6 \times 10^6\ \text{J}}{1\ \cancel{\text{kW·h}}}\right)$ $= 8.1 \times 10^6\ \text{J}$ $= 8.1\ \text{MJ}$

(b) Since there are 365 days in a year, the annual energy consumption is 365 times the daily use:

$$\begin{aligned}\Delta E &= 365(2.25\ \text{kW·h})\\ &= 821.25\ \text{kW·h}\\ &= 8.2 \times 10^2\ \text{kW·h}\end{aligned}$$

Alternatively, without the answer from part (a), the problem is most easily done using kW·h, h, and kW. Calculate the power in kW and the total time in h:

$$\begin{aligned}P &= (450\ \cancel{\text{W}})\left(\frac{1\ \text{kW}}{1000\ \cancel{\text{W}}}\right)\\ &= 0.450\ \text{kW}\end{aligned} \qquad \begin{aligned}\Delta t &= 365(5.0\ \text{h})\\ &= 1825\ \text{h}\end{aligned} \qquad \begin{aligned}\Delta E &= P\Delta t\\ &= (0.450\ \text{kW})(1825\ \text{h})\\ &= 821.25\ \text{kW·h}\\ &= 8.2 \times 10^2\ \text{kW·h}\end{aligned}$$

Paraphrase

(a) The daily energy use is 2.3 kW·h, or 8.1 MJ.

(b) The annual energy consumption is about 820 kW·h. (This is about twice the energy consumption of a modern refrigerator.)

Both sets of units were easy to use for part (a). If part (b) were done alone, it would be easier to use kW·h, h, and kW because of the size of the numbers.

Practice Problems

1. Calculate the annual energy consumption, in kW·h, of a hair dryer that is rated at 1400 W and is used for 7.0 min every day.
2. A 60-W incandescent light bulb runs continuously for 100 days. Use 3 significant digits in your answers.
   (a) Calculate the amount of energy used, in joules and in kilowatt hours.
   (b) How much heat is produced if the bulb has an efficiency of 5.00 percent?
3. You run a washing machine (512 W) and an electric clothes dryer (5000 W) for 1.5 h each daily.
   (a) How much energy (in kW·h) do the two appliances use in one day?
   (b) How much energy (in kW·h) do they use in one year?

Answers

1. 60 kW·h
2. (a) 144 kW·h, 5.18×10^8 J
   (b) 137 kW·h, 4.92×10^8 J
3. (a) 8.3 kW·h
   (b) 3.02×10^3 kW·h

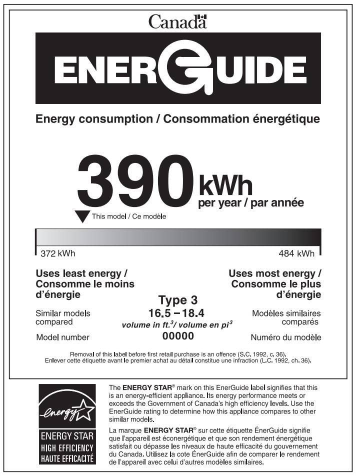
EnerGuide Labels

EnerGuide is Canada's official system for rating the energy consumption and efficiency of appliances, heating and cooling equipment, buildings, and vehicles. It helps consumers compare appliances by providing:

- an appliance's average annual energy consumption in kilowatt hours
- the annual energy consumption range for similar models
- the energy efficiency of the appliance relative to similar models

The technicians who establish EnerGuide ratings measure the power used by the appliance when it is running and the number of hours the appliance needs to run to do its task. For example, a dishwasher that runs at 1000 W for 1 h each day and a washing machine that runs at 500 W for 2 h each day both consume 1 kW·h in a day and 365 kW·h in a year. They would both get EnerGuide labels reading "365 kW·h per year." The lower the EnerGuide rating, the higher the savings; a dishwasher rated at 350 uses less energy than one rated at 365.

A shaded bar on the EnerGuide label shows the energy consumption of the most and least efficient appliances in the applicable class of appliances. An indicator arrow shows where within this range the energy consumption of the appliance falls. The farther the indicator is to the left end of the scale, the more efficient the appliance. Figure 6.29 shows the EnerGuide label for a refrigerator of high efficiency. The Energy Star symbol below the label shows that this is one of the most efficient appliances in its class. Efficiency of appliances has improved dramatically in recent years (Figure 6.30).



Canada

ENERGUIDE

Energy consumption / Consommation énergétique

390 kWh
per year / par année

This model / Ce modèle

372 kWh

484 kWh

Uses least energy / Consomme le moins d'énergie

Uses most energy / Consomme le plus d'énergie

Similar models compared

Type 3
16.5 – 18.4
volume in ft.^{3}/ volume en pi^3

Modèles similaires comparés

Model number

00000

Numéro du modèle

Removal of this label before first retail purchase is an offence (S.C. 1992, c. 36).
Enlever cette étiquette avant le premier achat au détail constitue une infraction (L.C. 1992, ch. 36).

ENERGY STAR
HIGH EFFICIENCY
HAUTE EFFICACITÉ

The **ENERGY STAR**® mark on this EnerGuide label signifies that this is an energy-efficient appliance. Its energy performance meets or exceeds the Government of Canada's high efficiency levels. Use the EnerGuide rating to determine how this appliance compares to other similar models.

La marque **ENERGY STAR**® sur cette étiquette ÉnerGuide signifie que l'appareil est éconergétique et que son rendement énergétique satisfait ou dépasse les niveaux de haute efficacité du gouvernement du Canada. Utilisez la cote ÉnerGuide afin de comparer le rendement de l'appareil avec celui d'autres modèles similaires.

Figure 6.29 The EnerGuide label states that this model of refrigerator uses about 390 kW·h of electrical energy in one year of normal operation.

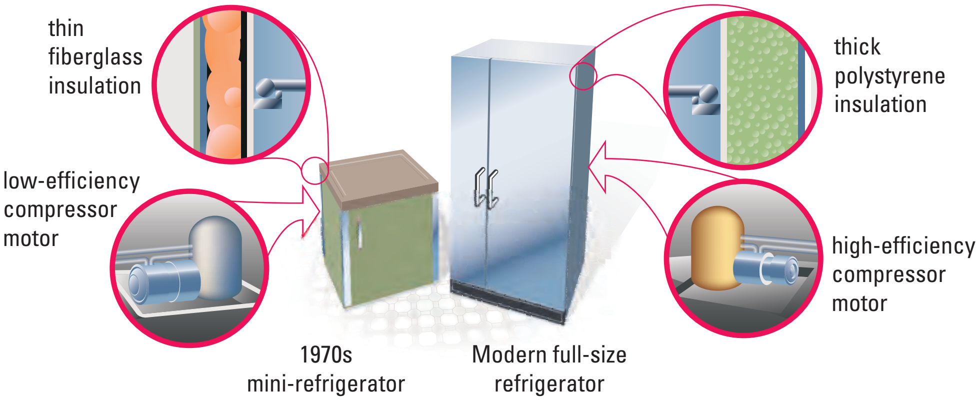


Figure 6.30 The energy used to run a mini-refrigerator in the 1970s can run a full-size refrigerator today. In the last 25 years, refrigerator efficiency has increased 300 percent.

The EnerGuide label not only helps Canadians reduce their energy costs, it contributes to a healthier environment by reducing the amount of electricity needed and thus the environmental effects associated with generating electricity.

PHYSICS•SOURCE

Take It Further

How much energy you burn cycling depends on the type of bicycle you use, the surface you ride over, the speed you cycle at, and more. Investigate formulas developed by kinesiologists to compute your energy consumption while cycling. Present your findings using an appropriate visual organizer.

Concept Check

1. An ad states: "This toaster uses only 1.5 kW/h." Explain what is wrong in this statement.
2. Why are appliance consumptions given in kW·h per year?
3. Explain why comparing energy consumptions is similar to comparing efficiencies.

C3 **Inquiry Activity**

PHYSICS•SOURCE

REQUIRED SKILLS
- Recording and organizing data
- Analyzing patterns

Efficiency of an Inclined Plane

Question

How does the efficiency of an inclined plane depend on its angle of inclination?

Activity Overview

Sliding a crate up a ramp is usually easier than lifting it straight up. In this activity, you will measure the work done sliding a block up an incline and compare it to the work needed for a vertical lift. The height of the ramp can be adjusted to see how the required applied force changes with the angle of the incline. You will determine which angle of inclination is the most efficient and which is easiest to use.

Your teacher will give you a copy of the full activity.

Prelab Questions

Consider the questions below before beginning this activity.

1. What do you need to measure to calculate the work you do dragging a block up a plane (Figure 6.31)?
2. Do you expect it will be easier to drag a block up a mild or steep incline? Explain your reasoning.

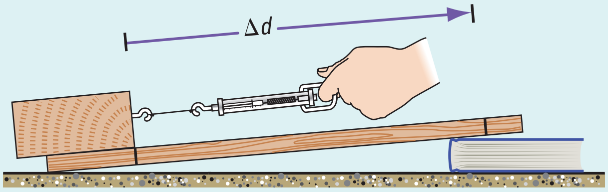


Figure 6.31 You will set up a wooden plank on one, two, three, and four books and use a spring scale to measure the force needed to slide a wooden block up the ramp.

C4 **Inquiry Activity**

PHYSICS•SOURCE

REQUIRED SKILLS
- Measuring
- Drawing conclusions

Power Running Up Stairs

Question

What is the maximum power that you can develop running up stairs?

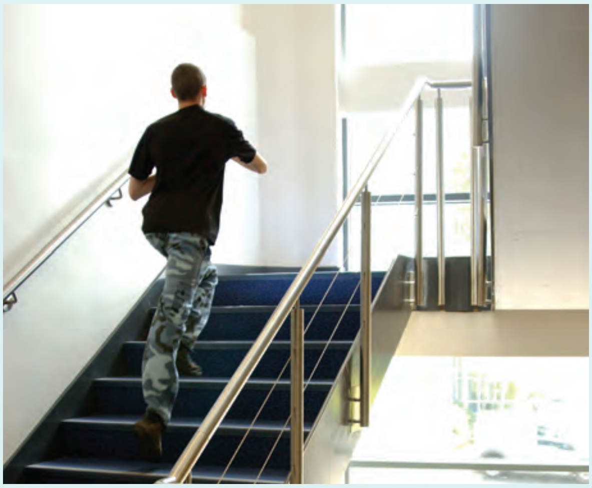


Figure 6.32 You will measure the height of the stairs to determine the vertical height you will rise.

Activity Overview

The human body is a machine. The food you eat is the input energy. The work you perform moving your body and external objects is the output energy. The difference between the input and output energies is energy that is used to power the systems in your body. In this activity, you will calculate the work you did and the power you developed running up stairs. You will also compare the power you developed with the power developed by other students.

Your teacher will give you a copy of the full activity.

Prelab Questions

Consider the questions below before beginning this activity.

1. Imagine running up a flight of stairs. What measurements will you need to make to determine your power?
2. How do you think your power running up stairs will compare to that of a 100-W light bulb?

6.2 Check and Reflect

Key Concept Review

1. What is the relationship between the amount of work that is done by a device and its power?

2. How is it possible for a person to be strong but not powerful? Use an example to illustrate your answer.

3. Why is it impossible for a machine to have an efficiency of 100 percent?

4. Why can an electric heater be 100 percent efficient?

5. An air conditioner uses 1500 J of energy each second. Explain why this does not violate the law of conservation of energy.

6. A laser printer is rated at 250-W input. What types of energy do you consider useful output for a printer? What types of energy are waste?

7. High-impact aerobics is rated at 413 kcal per hour. Explain whether this is a measurement of energy or power.

8. (a) Explain this statement: Humans have an efficiency of about 10 percent.
(b) Describe how the body uses the other 90 percent of the input energy.

9. Describe two non-SI units for energy. Under which common circumstances are these units used?

10. Why might you want to know the input power of a device? Why might you want to know the output power of a device?

11. Which produces more light: a 60-W light bulb that is 5 percent efficient or a 30-W light bulb that is 15 percent efficient? Explain.

12. A crane lifts a 756-kg girder 23.5 m in 45.2 s. Calculate the output power of the crane.

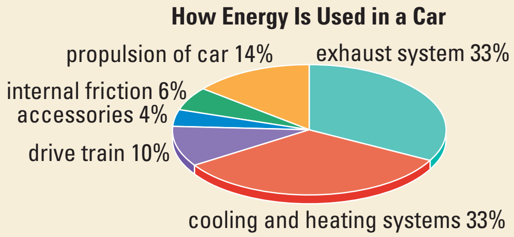
Connect Your Understanding

13. A car engine exerts a force of 4250 N to accelerate a car over a distance of 112 m in 8.23 s. Calculate the power of the engine in watts and in kilowatts.

14. An electric motor has a power rating of 1.50 kW. If it operates at 75 percent efficiency, what work can it do in an hour? Answer in J and in kW·h.

15. Playing tennis is rated at 440 W. How much energy is consumed playing tennis for 20.0 min? Give your answer in kJ and in kcal.

16. The graph below shows the energy consumed by the various components in an automobile from the combustion of gasoline.



Question 16

(a) Which consumption categories do you consider to be "useful" energy? Explain.
(b) Estimate the efficiency of the automobile for converting chemical energy into the car's kinetic energy.

17. An electric can opener is rated at 120 W. How much energy does the can opener consume in a year when used 1.5 min/day?

18. The cryogenic magnets at the Large Hadron Collider are rated at 27.5 MW. How much energy (in GW·h and in J) do the magnets consume in 30.0 days of continuous use?

19. A dishwasher has a 40.0-min wash cycle (200 W) and a 30.0-min dry cycle (1200 W). How much energy is used to run the dishwasher (both cycles) daily for a year? How much electricity would you save by just using the wash cycle?

20. Why does EnerGuide quote appliance ratings in kW·h per year rather than simply in watts?

Reflection

21. Describe a daily task you perform efficiently. Describe a task you do inefficiently. Do you think the common meaning of "efficiency" is close to the physics meaning? Explain.

22. Describe a concept from this section that you found difficult to understand. What resources or strategies might help you to resolve the difficulty?

For more questions, go to PHYSICS•SOURCE

6.3 Kinetic Energy and Electricity Generation

Section Summary

- Ontario uses many technologies to generate electricity.
- Each energy technology has advantages and disadvantages.
- Hydroelectric plants transform the gravitational potential energy of falling water into the mechanical energy that turns the rotors in generators.
- Wind turbines transform kinetic energy of air into electrical potential energy.

Figure 6.33 Much of southern Ontario lost power on a hot afternoon in the summer of 2003. The outage was caused by problems at a power plant in Ohio. Transmission fluctuations spread quickly throughout the electricity grid, knocking out power over a wider and wider area. The blackout eventually affected an estimated 10 million people in Canada and 45 million people in the U.S.

Statistics Canada later reported that 2.4 million workers in Ontario and Quebec lost 26.4 million hours of work that August, either directly or indirectly because of the power outage.

Photographs (a) and (b) contrast the Toronto skyline before and during the blackout.

On the afternoon of August 14, 2003, in response to a massive fluctuation in the power transmission grid, hundreds of generating stations and power plants across the northeastern and midwestern United States and Ontario shut down (Figure 6.33). People were stuck in elevators and on the subway. Air conditioners cut out in homes and offices, and emergency generators clicked on in hospitals. That night, neighbours had freezer barbecue parties, consuming rapidly thawing food while seeing the Milky Way for the first time ever from their city backyards.

Electricity generation is the process in which other forms of energy, such as mechanical energy, are transformed into electrical potential energy. This electrical energy is then delivered to consumers through a transmission network, called a *grid*.

Ontario generates, transmits, and consumes a huge amount of electrical energy. Electrical power plants have output power ratings ranging from a few kilowatts to thousands of megawatts ($1\ \text{MW} = 1 \times 10^6\ \text{W}$). Electrical energy generated is often quoted in megawatt hours (1 MW·h = 1×10^3 kW·h) or gigawatt hours (1 GW·h = 1×10^3 MW·h = 1×10^6 kW·h). Ontario's total electricity production in 2008 was 1.6×10^8 MW·h, enough to meet almost all Ontario's demand for energy.

Ontario's two largest sources of electrical energy are nuclear and hydropower (Figure 6.34). **Hydropower** is power generated by harnessing the energy of moving water. Electricity generated by hydropower is called "hydroelectricity," or simply "hydro."

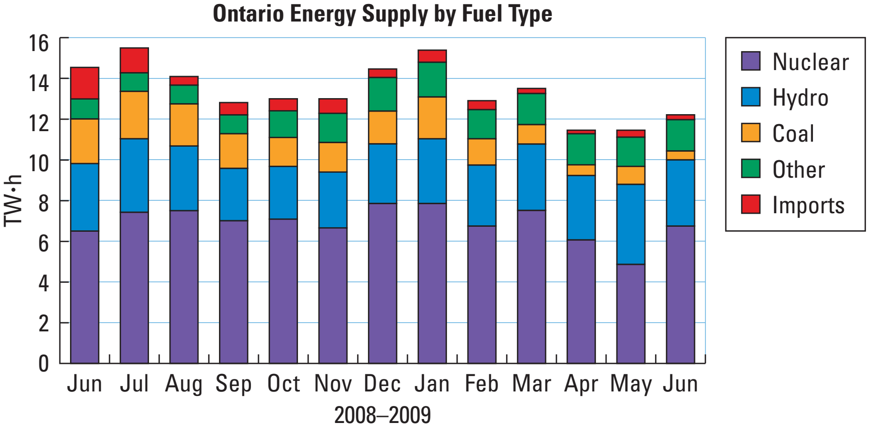


Figure 6.34 Ontario generates about 53 percent of its electricity from nuclear reactors, 25 percent from hydro projects, and 22 percent from fossil fuels.

Energy Resources

Just as energy is not destroyed when it is consumed, energy is not created when electricity is generated. All the energy in the universe has existed since the beginning of time. Many of the forms of energy we use can be traced back to the formation of the Sun:

- Fossil fuels and biomass materials were once living organisms whose energy came from the Sun.
- The running water of rivers and the wind are parts of the climate cycles, driven by the Sun's energy.
- Nuclear energy is released in nuclear reactions. Nuclear fission of uranium powers nuclear reactors. The energy of the Sun itself comes from nuclear fusion.
- Geothermal energy is heat from inside Earth produced by radioactive decay of many heavy elements.
- The gravitational energy of the Earth–Moon–Sun orbital system becomes tidal energy.

Energy sources are often called **energy resources**. A **renewable** energy resource (Figure 6.35) is one that is continually replaced by nature; for example, wind energy and tide energy. A **non-renewable** energy resource (for example, coal) has a limited supply. Canada's major energy resources are summarized in Table 6.8. Wind, hydroelectric, and tidal resources are used almost exclusively for electricity generation. The other resources are used for electricity generation, industrial processes, transportation, and heating. The technology needed to generate electricity differs for

Figure 6.35 Across Canada, renewable energy resources such as wind, solar, biomass, and tides produce ever-increasing amounts of electricity each year. Wind farms present a collision risk to birds and bats, but do not have any noticeable impact on livestock.

each resource, and the efficiency of resources as electricity producers varies widely. Where heat is a by-product of generating electricity, it is often used by industry.

Which resource best meets the electricity needs of a community depends largely on local geography: Is there a waterfall? Is there water for cooling? Is there enough wind? However, the use of each type of resource has different impacts on society and the environment. These factors become part of the decision-making analysis as well.

Hydroelectric, tidal, and wind generation of electricity rely on the kinetic energy in the natural flow of water or air. These technologies are discussed in this section. Steam power plants are fuelled by fossil fuels, biomass materials, or heat from nuclear reactions. Electrical energy generation related to heat is discussed in Chapter 7. The nuclear physics of thermonuclear generation is discussed in Chapter 8.

PHYSICS•SOURCE

Suggested Activity

- C5 Case Study Overview on page 202

Table 6.8 Canada's Major Energy Sources

Energy Resource	**Fundamental Energy Source**	**Efficiency Producing Electricity**	**Advantages**			**Disadvantages**
			Renewable	**Green***	**Other**	
Fossil fuels	Sun (nuclear fusion)	40%			known technology; can cycle on-off	air pollution; greenhouse gases; limited supply
Wind		45%	✓	✓	small and local	special site requirements; variable production
Biomass		variable	✓			agricultural land removed from food production; air pollution
Hydro (moving water)		95%	✓	✓	can cycle on-off	nearly at capacity; environmental damage from dams
Direct solar		12%	✓	✓	better efficiency for heating	initial expense; variable output; Canadian climate not suited for large-scale electricity generation
Nuclear (reactors)	nuclear fission	30%		✓	high-tech employment	environmental (mining, processing and waste storage of radioactive material); risk of nuclear accidents; can't cycle on-off
Geothermal	radioactive decay	variable		✓	good ground-source technology for heating	lack of geologically active sites for large-scale electricity generation
Tidal	E_g of Earth–Moon–Sun	85%	✓	✓		only on the coasts; environmental issues in tidal basins

* **Green energy sources** have no carbon footprint (after construction has been completed) and are non-polluting.

Concept Check

1. What does it mean to "generate" electrical energy?
2. Name three energy resources used to generate electricity.
3. Explain why it might be preferable to use a renewable rather than a non-renewable resource.

Hydroelectric Generation

At present, all major methods of generating electricity use moving fluids to turn a turbine that drives an electromagnetic generator (Figure 6.36).

A **turbine** is a mechanical device, similar to a water wheel, that has blades to catch the motion of a passing fluid (water or a gas). The turbine then transfers energy through a drive shaft to the generator, which converts mechanical energy into electrical potential energy.

In hydro generation, large intake pipes divert water from the top of a waterfall or drain it from a reservoir behind a high dam. The gravitational potential energy in the water is transformed into kinetic energy as the water falls down the penstock to the turbines. As the water pushes through the turbines, the energy is transferred to the generator and electricity is produced. Eventually, the water, now moving much more slowly, emerges from the bottom of the station.

The power available from a hydro plant depends on the height from which the water falls, the amount of water passing through the turbines per unit time, and the combined efficiency of the plant's turbines and generators (Figure 6.36).

An output power of a few hundred kilowatts, as in Example 6.12, is typical of a small hydro plant. Ontario has many small hydro plants with a capacity under 10 MW. In contrast, the three large hydroelectric stations at Niagara Falls (one of which is shown in Figure 6.37) have a combined capacity of 2400 MW.

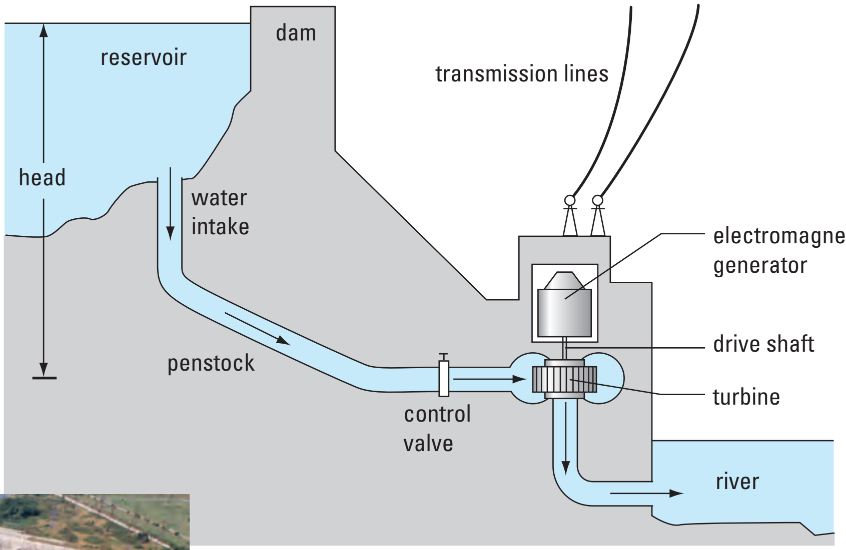


Figure 6.36 A hydroelectric generating plant. The amount of potential energy in water is proportional to the *head* — the difference in height between the source and the turbine.

Figure 6.37 Adam Beck 1 hydroelectric generating station at Niagara Falls, the largest source of hydroelectric power in Ontario. Hydroelectric plants are between 85 and 95 percent efficient at converting the energy of moving water into electrical energy. While the actual generation of electricity is environmentally friendly, the diversion and damming of water needed to develop a hydro project can be devastating to local ecosystems and human populations.

Example 6.12

At a hydro project, the water drops 70 m from the intake pipes to the turbines. Calculate the electrical power generated by each tonne of water that flows through the station each second. Assume an efficiency of 90 percent.

Given

$$\begin{aligned} h &= 70\ \text{m} \\ m &= 1\ \text{t} = 1000\ \text{kg} \\ \Delta t &= 1\ \text{s} \\ \textit{Efficiency} &= 90\% = 0.90 \end{aligned}$$

Required

power input (P_{in})
power output (P_{out})

Analysis and Solution

Calculate the gravitational potential energy of 1 t of water before it enters the station, using the turbines as the reference level. This energy is the input energy of the turbines.

$$\begin{aligned} \Delta E_{\text{g}} &= E_{\text{g}} \\ &= mgh \\ &= (1000\ \text{kg})\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)(70\ \text{m}) \\ &= 6.867 \times 10^5\ \text{J} \end{aligned}$$

$$\begin{aligned} P_{\text{in}} &= \frac{\Delta E_{\text{in}}}{\Delta t} \\ &= \frac{6.867 \times 10^5\ \text{J}}{1\ \text{s}} \\ &= 6.867 \times 10^5\ \text{W} \end{aligned}$$

Calculate the power output.

$$\begin{aligned} P_{\text{out}} &= P_{\text{in}} \times \textit{Efficiency} \\ &= (6.867 \times 10^5\ \text{W})(0.90) \\ &= 6.180 \times 10^5\ \text{W} \\ &= 6.2 \times 10^5\ \text{W} \end{aligned}$$

Paraphrase

The output power of the hydro station is about 6.2×10^5 W from each tonne of water per second.

Practice Problems

1. In a small hydro installation, 25 t of water pass through the penstock each minute, dropping 30 m to the turbines below. Assuming an efficiency of 95 percent, determine the power output of the plant.
2. In another hydroelectric plant, 250 m^3 of water pass through the turbines every minute. The plant is rated at 540 kW output power. How far does the water fall? Assume 100 percent efficiency, and assume that 1 m^3 of water = 1 t.
3. Repeat problem 2, assuming the efficiency is 90 percent.

Answers

1 1.2×10^5 W

2. 13.2 m

3. 15 m

Concept Check

1 Describe the energy transformations during hydroelectric generation.

2. What factors determine the output power of a hydro plant?

3. Describe an environmental problem associated with hydroelectric generation.

PHYSICS•SOURCE

Suggested Activity

- C6 Decision-Making Analysis Overview on page 202

PHYSICS INSIGHT

The amount of air caught by a wind turbine depends on the area the rotor blades sweep out. The r^2 in the wind power formula is related to this area.

Figure 6.38 The ExPlace wind turbine is 90 m tall to the tip of the blade and has a rotor diameter of 52 m. It has a normal rotation speed of 24.5 revolutions per minute and can generate about 500 kW of electrical power in winds of 11 m/s.

Practice Problems

1. What is the output power of the ExPlace wind turbine (Figure 6.38) in the following wind speeds?
   (a) 15 km/h (b) 30 km/h
2. What is the output power in a 20-m/s wind of a turbine with the following rotor diameters?
   (a) 10 m (b) 20 m

Answers

1. (a) 27 kW (b) 2.2×10^5 W
2. (a) 1.1×10^5 W (b) 4.4×10^5 W

Wind Power

Wind is everywhere, it is free, and it is both renewable and non-polluting. Individual wind turbines rated at a few kilowatts are now a common source of electricity for people who live off the power grid. Ontario also has a number of wind farms, some rated at almost 200 MW. As of 2008, Ontario had developed 780 MW of wind generation capacity, the highest of all the provinces.

The modern wind turbine is a system of rotor blades that catch the wind and gears that control the rotation speed of the blades. Typical turbine efficiencies are about 45 percent. This is only about 50 percent of the efficiency of hydroelectric systems.

Two main factors determine how much power a turbine can produce: the radius of the rotor blades and the speed of the wind (Figure 6.38). An approximate formula for the output power of a wind turbine is

$$P = \left(0.556\ \frac{\text{kg}}{\text{m}^3}\right) r^2 v^2$$

where P is the power in watts, r is the rotor blade radius in metres, and v is the wind speed in metres per second.

Example 6.13

Find the output power in 40-km/h wind of a small wind turbine that has a rotor blade diameter of 2.5 m.

Given

$d = 2.5$ m
$v = 40$ km/h

Required

power output (P_{out})

Analysis and Solution

Find the rotor radius (m) and the wind speed (m/s). Then use the formula $P = \left(0.556\ \frac{\text{kg}}{\text{m}^3}\right) r^2 v^2$.

$$\begin{aligned} r &= \frac{d}{2} \\ &= \frac{2.5\ \text{m}}{2} \\ &= 1.25\ \text{m} \end{aligned}$$

$$\begin{aligned} v &= 40 \frac{\cancel{\text{km}}}{\cancel{\text{h}}} \times \frac{1\ \cancel{\text{h}}}{3600\ \text{s}} \times \frac{1000\ \text{m}}{1\ \cancel{\text{km}}} \\ &= 11.11\ \text{m/s} \end{aligned}$$

$$\begin{aligned} P &= \left(0.556\ \frac{\text{kg}}{\text{m}^3}\right) r^2 v^2 \\ &= \left(0.556\ \frac{\text{kg}}{\cancel{\text{m}^3}}\right) (1.25\ \text{m})^2 \left(11.11\ \frac{\cancel{\text{m}}}{\text{s}}\right)^3 \\ &= 1192\ \text{W} \\ &= 1.2\ \text{kW} \end{aligned}$$

Paraphrase

The turbine has an output power of about 1.2 kW.

Concept Check

1. Explain how a turbine converts kinetic energy from the wind to mechanical energy.
2. What factors determine the output power of a wind turbine?
3. Describe one advantage of wind generation.

PHYSICS•SOURCE

Take It Further

Meteorologists measure wind strength and variability all over Earth, recording the data in wind atlases. Find out if your area is appropriate for wind technology by checking an Ontario wind atlas, and report your finding.

Tidal Power

Twice daily, the highest tides in the world slosh into and out of the Bay of Fundy. Each time, an area of about 16 000 km^2 is flooded by water up to 20 m deep. Power utilities in Nova Scotia and New Brunswick are eager to tap into this enormous wet supply of kinetic and gravitational potential energy.

A pilot tidal project, opened in 1984 in Annapolis Royal, Nova Scotia, is generating 20 MW of electrical power. At present, the largest tidal station in the world is located in France, on the estuary of the Rance River, and is rated at 240 MW. These power plants work on the same basic concept. A low dam (called a *tidal barrage*) is built across a natural tidal basin or river estuary. Sluice gates allow the incoming tidal water to pass into the large collection area. The gates are closed at high tide. Later, the water runs out through turbines connected to generators. One downside to this design is that it causes major changes to water flow in creeks, wetlands, and estuaries, affecting large areas of wildlife habitat.

The turbine shown in Figure 6.39 is part of a newer tidal technology. Underwater turbines are mounted on the seabed in locations where the tidal currents are particularly strong. The turbines operate in a similar fashion to wind turbines but produce more power per unit area. This is because water carries much more kinetic energy than air moving at a similar speed. This technology is also being used for small generators that can be placed in fast-moving creeks to generate electricity in off-grid remote locations.

Figure 6.39 Each day, 100 billion tonnes of seawater flow in and out of the Bay of Fundy — more than the combined flow of the world's freshwater rivers. Underwater turbines like this one will soon generate up to 300 MW of electrical power — enough to power almost 100 000 homes.

C5 Case Study

REQUIRED SKILLS
- Selecting and recording information
- Reporting results

Fuel Cells

Issue

Is a stationary fuel cell an appropriate power technology for a wildlife monitoring station?

Activity Overview

In this activity, you will consider the technical and environmental requirements for power at a proposed remote research station. Generators are a proven technology but they are noisy and burn fossil fuel. **Fuel cells** are electrochemical cells that convert fuel such as oxygen and hydrogen into water and electricty. You and your group must recommend whether fuel cells or generators (either gasoline or diesel) are more appropriate for this project.

Your teacher will give you a copy of the full activity.

Prelab Question

Consider the question below before beginning this activity.

1. To determine an appropriate source of electricity for the station, what information will you need to know about (a) generators and (b) fuel cells?

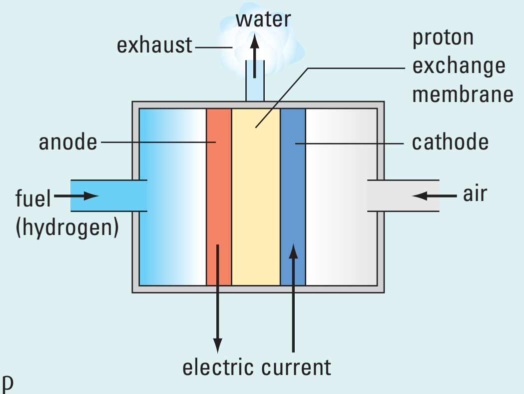


Figure 6.40 A hydrogen fuel cell uses oxygen from the air and hydrogen as the reactants and produces water and electricity. Hydrogen fuel cells are clean, quiet, and come in a range of sizes.

C6 Decision-Making Analysis

REQUIRED SKILLS
- Determining bias
- Summarizing information

Green Energy — Wind

Issue

Should wind energy be considered a source of green energy, given the environmental and societal issues raised by some wind farm projects?

Activity Overview

Ontario's electricity generation capacity derived from wind energy is growing dramatically. You will research the advantages and disadvantages of wind energy. In particular, you will examine issues related to noise, birds, property rights, and government accountability. You will determine if wind power is environmentally friendly and ethically responsible. Also, you will make recommendations for actions to help wind power become an acceptable energy resource for Ontario.

Your teacher will give you a copy of the full activity.

Prelab Questions

Consider the questions below before beginning this activity.

1. What are some of the advantages of wind energy?
2. What are some of the disadvantages?

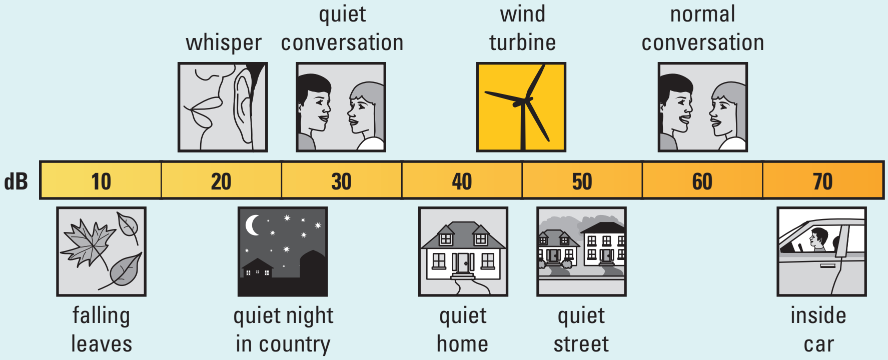


Figure 6.41 The decibel (dB) is the unit used to measure the relative loudness, or intensity, of sound. On the decibel scale, the smallest audible sound (near total silence) is 0 dB. A sound 10 times more powerful is 10 dB. A sound 100 times more powerful than near total silence is 20 dB. The sound level on a quiet night in the country is around 25 dB. A wind farm generating 45 dB is creating sound around 100 times louder than the sound on a quiet country night.

6.3 Check and Reflect

Key Concept Review

1. Explain the expression "generate energy."
2. What is Ontario's largest energy source for electricity?
3. Which energy resources get their energy from the Sun?
4. (a) Give three examples of renewable energy resources.
   (b) Give three examples of non-renewable energy resources.
5. Describe three factors to be considered when choosing a method of generating electrical energy.
6. Ontario's total electricity production in 2008 was 1.6×10^8 MW·h. Give this amount in kW·h and J.
7. Which methods of electrical energy generation start with kinetic energy?
8. What are the main parts of a hydroelectric plant?
9. Describe the energy transformations that occur in a hydroelectric plant.
10. Describe the main factors that determine the amount of electricity generated by a hydroelectric plant.
11. Explain the following statement: A small hydroelectric plant has a capacity of 10 MW.
12. Describe the main factors that determine the power generated by a wind turbine.
13. (a) List three ways in which hydro and wind generation are similar.
    (b) List three ways in which hydro and wind generation are different.

Connect Your Understanding

14. Why has hydroelectric generation been so popular in Ontario?
15. Most hydroelectric plants are about 95 percent efficient. Where do energy losses occur?
16. A hydroelectric project produces 1.5 GW. Assuming the generators run continuously, how much electrical energy is produced in a day?
17. What mass of water must pass through a hydroelectric station each 1.00 s to produce 855 kW of electricity from a 34.6 m drop? Assume no energy losses.
18. How would your answer in question 17 change if the efficiency were less than 100 percent? Explain.
19. CERN is located in Geneva, Switzerland, which has an annual electricity production of 41 PJ.
    (a) Convert 41 PJ to TW·h.
    (1 petajoule (PJ) = 1×10^{15} J)
    (b) CERN used about 1000 GW·h of electricity in 2009. What percentage of Geneva's production is this?
20. Wind is used to generate electricity. Give another practical use for wind power.
21. Wind farms are often located on the edge of large bodies of water. Why?
22. Most wind turbines have an efficiency of about 45 percent. Where does the missing energy go?
23. Determine the output power of a wind turbine with 3.2-m blades in a 25-km/h wind.
24. Which produces more electricity: one wind turbine with 15-m blades or two wind turbines with 10-m blades? Explain.

Reflection

25. What are two things you would like to know more about after reading about electricity generation?
26. Of the information provided in this section about renewable energy resources, which parts did you find the most interesting?

For more questions, go to PHYSICS•SOURCE

CHAPTER 6 CHAPTER REVIEW

Key Concept Review

1. Give an example to illustrate the difference between work and energy. ⓚ
2. For each situation, explain whether the work you do is positive, negative, or zero:
   (a) You push a chair across a carpet. ⓚ
   (b) You pull a suitcase along a sidewalk. ⓚ
   (c) You carry a baby along a hallway. ⓚ
   (d) You carry a box downstairs. ⓚ
   (e) You glide to rest on skates. ⓚ
3. A golf club exerts a force of 42.3 N on a golf ball over 2.52 m.
   (a) How much work is done by the golf club? ⓚ
   (b) Describe the energy transfers and transformations that occur when you hit a golf ball with a golf club. ⓚ
4. Compare the kinetic energies of a 45.9-g golf ball moving at 66.2 m/s and a 145-g fastball moving at 44.3 m/s. ⓚ
5. Explain why these objects have the ability to do work:
   (a) sliding curling rock ⓚ
   (b) jar of pickles on high shelf ⓚ
   (c) stretched elastic band ⓚ
6. You lift a 6.52-kg turkey from the floor to the kitchen counter 82.5 cm up.
   (a) How much work do you do? ⓚ
   (b) Find the change in gravitational potential energy of the turkey. ⓚ
   (c) Describe another way to find the answer in part (b). ⓚ
7. Describe three types of mechanical energy. ⓚ
8. Use an example to explain the difference between an isolated and a non-isolated system. ⓚ
9. State two versions of the law of conservation of energy. ⓚ
10. Explain the difference between power and energy. ⓚ
11. Show that $1\ \text{W} = 1\ \dfrac{\text{kg}\cdot\text{m}^2}{\text{s}^3}$. ⓚ
12. A forklift has an efficiency of 55 percent. How much energy does it need to do 1.6 kJ of work? ⓚ
13. Give an example to explain the expression “consume energy.” ⓚ
14. Calculate the amount of energy (in J) used by a 200-W television in 3.00 h. ⓚ
15. A 70.0-kg person playing competitive badminton for 30.0 min uses about 250 kcal.
   (a) How much energy (in J) is used each second? ⓚ
   (b) What is the input power rating (in W) for this activity? ⓚ
16. Show that $1\ \text{kW}\cdot\text{h} = 3.6 \times 10^6\ \text{J}$. ⓚ
17. A modern refrigerator runs at 112 W for 7.00 h each day. Calculate its consumption rating (in kW·h per year). ⓚ
18. Describe the information given on an EnerGuide label. ⓚ
19. Canada’s energy consumption was about 1500 TW·h in 2008. Convert this to joules. ⓚ
20. Explain the following statement: Canada’s capacity for wind power has reached 2400 MW. ⓚ
21. (a) Compare the typical efficiencies of hydro and wind power. ⓚ
   (b) Explain why these efficiencies are so different. ⓚ
22. Describe three environmental and three non-environmental factors to be considered when choosing a method with which to generate electricity. ⓚ

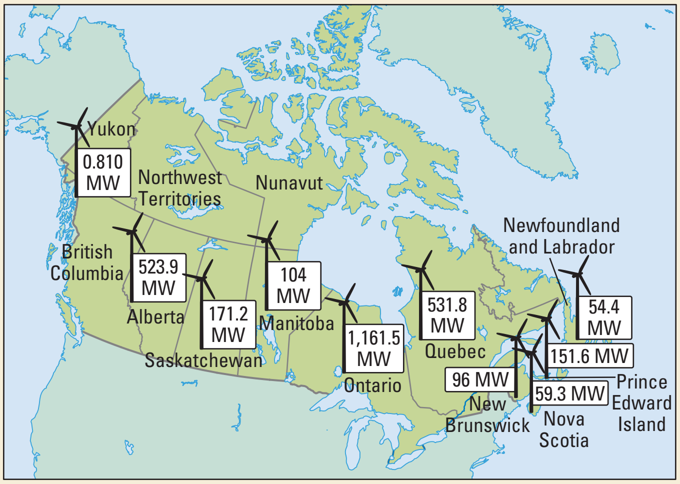
Connect Your Understanding

23. A ball is thrown and hits a brick wall.
   (a) Does the ball do work on the wall? Explain. ⓐ
   (b) Does the wall do work on the ball? Explain. ⓐ
24. (a) When you flip a penny (2.35 g), it leaves your hand and moves upward at 2.85 m/s. Use energy to find how high the penny goes above your hand before stopping. ⓐ
   (b) The penny then falls to the floor, 1.26 m below your hand. Use energy to find its speed just before it hits the floor. ⓐ
   (c) Explain your choice of reference level for parts (a) and (b). ⓒ
   (d) Choose a different reference level and repeat part (b). ⓐ

ACHIEVEMENT CHART CATEGORIES

ⓚ Knowledge and understanding
ⓣ Thinking and investigation
ⓒ Communication
ⓐ Application

25. The diagram below shows the wind generation capacity by region in Canada:
(a) Is capacity a measure of energy or power? Explain. ⓒ
(b) Why is there no wind generation in British Columbia? ⓣ
(c) Identify a province that has both the ability and need for greater wind capacity. Justify your choice. ⓣ



Question 25

26. You pull a toboggan loaded with friends for 16.3 m through deep snow.
(a) How much work do you do if you apply a horizontal force of 348 N? ⓐ
(b) The toboggan feels a 325 N force of friction. Find the work done by friction. ⓐ
(c) Describe the motion of the toboggan. ⓒ
(d) Describe the energy transformations that occur. ⓒ

27. A roller-coaster train and its passengers have a combined mass of 1250 kg. The train comes over the top of the first hill, 53.2 m above the ground, with a speed of 1.17 m/s.
(a) The train goes down the first hill and through a loop. Ignoring friction, calculate the speed of the train at the top of the loop, 21.3 m above the ground. ⓐ
(b) Before applying its brakes at the end of the ride, the train moves along a level stretch of track 2.71 m above the ground. The train's speed is 24.3 m/s. How much mechanical energy has been lost during the ride? Where did this energy go? ⓐ

28. (a) A blender is rated at 400 W. How much energy (in J) does the blender use in 1.5 min? ⓐ
(b) The blender is about 60 percent efficient. How much work does it do in 1.5 min? ⓐ
(c) What energy transformations make up the remaining 40 percent? ⓒ

29. A 70.0-kg person walks up stairs at 75 steps per minute. The height of each step is 18.0 cm.
(a) Calculate the person's output power. ⓐ
(b) The person burns 563 kcal per hour walking up stairs. Convert this power rating into watts. ⓐ
(c) Find the efficiency of this person walking up stairs. ⓚ

30. (a) Assume you need to cool your bedroom for 8.5 h/day for 63 days each summer. Compare the energy consumed using a ceiling fan (100 W), a room air conditioner (1000 W), and a central air unit (3000 W). ⓐ
(b) Other than cost, why might you want to reduce the amount of air conditioning you use? ⓒ

Reflection

31. How would you have defined energy before you began this chapter? Describe several ways in which your understanding of energy has changed during this chapter. ⓒ

32. How has your understanding of the different types of energy changed after reading this chapter? Identify two things about energy you did not know before reading this chapter. ⓒ

Unit Task Link

Living and working consumes energy, either from electricity or some other source. Your task is to estimate the energy consumption at a remote retreat centre. First, you will need to determine how many people use the retreat, in what seasons, and to what level of comfort. Basic needs (such as heat, lighting, cooking, water, and laundry) must be covered. Prepare a summary of the household systems (for example, cooking appliances) needed, and estimate the annual energy consumption of each system.

For more questions, go to PHYSICS•SOURCE