8

Kinetic and Potential Energy

KEY IDEA

Kinetic and gravitational potential energy are interchangeable. The total amount of energy in an isolated system is conserved.

PHYSICS AROUND US . . . The Roller Coaster

While visiting your local amusement park, you and your friends decide to take a ride on the roller coaster. You climb into a car, strap yourself in, and wait while an electric motor lifts the car slowly, overcoming the force of gravity that tries to pull you back down. Then you experience that breathless moment at the top, when you are poised to plunge downward but haven't quite started the scary descent.

With a whoosh of air (and perhaps a few screams from some riders), you plummet back toward Earth, careening faster and faster as you descend. At the last moment, the track changes direction and you start up again, repeating the sequence until the ride ends.

You may think of the ride as just good fun, but you have actually transformed yourself into a living demonstration of one of the most important features of nature—the transformation of energy from one form to another. This phenomenon underlies interactions throughout all of science, from the tiniest particles to the largest galactic clusters, from biology to chemistry to geology, from the sunlight that wakes you up in the morning to the electric lamp you turn off before going to sleep at night. The interchangeability of energy from one form to another is a powerful idea whose many implications we explore in the next several chapters.

WORK, ENERGY, AND POWER: WORDS WITH PRECISE MEANINGS

Whenever you ride in a car, climb a flight of stairs, or just take a breath, you use energy. At this moment, trillions of cells in your body are hard at work turning yesterday's food into the chemical energy that keeps you alive today. Energy in the atmosphere is generating sweeping winds and powerful storms, while the ocean's energy drives mighty currents and incessant tides. Meanwhile, deep within the Earth, energy in the form of heat is moving the very continent on which you are standing.

A turbulent sea is one of the greatest sources of energy on Earth.

Energy is all around you—in the ever-shifting atmosphere and restless seas, in simple bacteria and mighty redwood trees, in brilliant sunlight and shimmering moolight. Energy affects everything in the physical world, and the laws that govern its behavior are among the most important and overarching concepts in science.

In every situation where energy is expended you will find one thing in common. If you look at the event closely enough you will find that, in accord with Newton's laws of motion (Chapter 4), a force is exerted on an object to make it move. When your car burns gasoline, the fuel's energy ultimately turns the wheels of your car, which then exert a force on the road; the road exerts an equal and opposite force on the car, pushing it forward. When you climb the stairs, your muscles exert a force that pushes down on the stairs, enabling you to move upward against gravity. Even in your body's cells, forces are exerted on molecules in chemical reactions. Energy, then, is intimately connected with the application of a force.

In everyday conversation, we may speak of a small child's seemingly inexhaustible energy, of a song that sounds energetic, or of an athlete being energized. In physics, the term *energy* has a precise definition that is somewhat different from the ordinary meaning. However, to see what physicists mean when they talk about energy, we must first introduce the concept of *work*.

Work

In the lexicon of physics, we say that **work** is done whenever a force is exerted over a distance. When you picked up this book, for example, your muscles applied a force equal to the weight of the book over a distance of a foot or so. You did work (Figure 8-1).

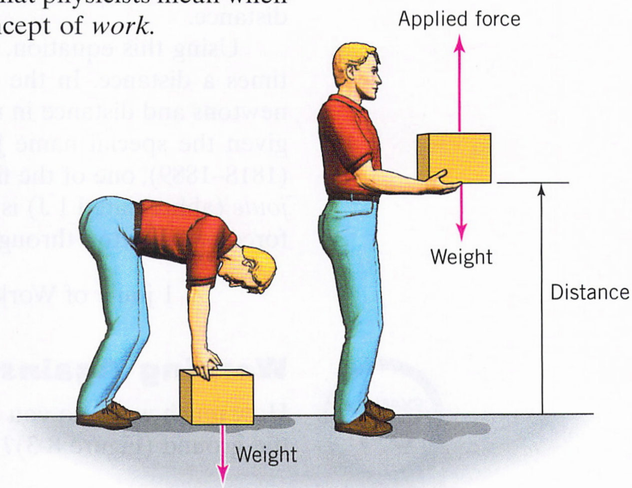


FIGURE 8-1. Work is done whenever a force is exerted over a distance.

This definition of *work* differs considerably from everyday use. From a physicist's point of view, if you accidentally drive into a stone wall and smash your fender, the wall does work because a force deformed the car's metal a measurable distance. On the other hand, a physicist would say that you haven't done any work if you spent an hour in a futile effort to move a large boulder, no matter how tired you got. Even though you have exerted a considerable force, the distance over which you exerted it is zero.

There's another way in which a force can do no work. Imagine carrying a briefcase as you walk along a flat street at a steady pace. In order to hold the briefcase, your hand exerts an upward force on it. But the briefcase moves in a direction perpendicular to that force, so that force does no work! You should keep in mind that when we talk about a force doing work, we really mean the part of the force that points in the direction of the motion. If there is no motion, or if the force is perpendicular to the motion, the work is zero.

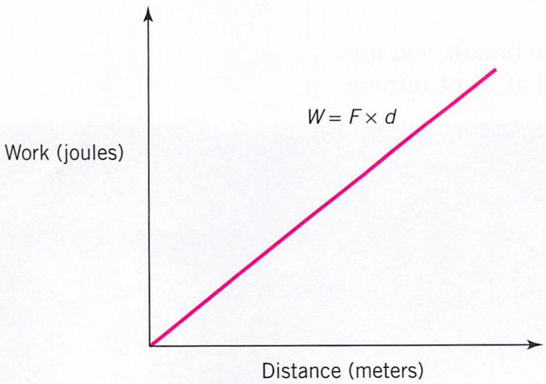


FIGURE 8-2. The direct relationship between work and distance illustrated in graphical form.

It's also possible for work to be negative. For example, the gravitational force exerted on you as you climb a flight of stairs does negative work because you're moving up and the force is pulling down. If the force and the motion are in opposite directions, then the work done by that force is negative.

Physicists provide an exact mathematical definition to their notion of work.

1. In words:

Work is done whenever a force is exerted over a distance. The amount of work done is proportional to both the force and the distance.

2. In an equation with words:

Work (in joules) = Force (in newtons) × Distance (in meters)

where a joule is the unit of work, as defined next.

3. In an equation with symbols:

$$W = F \times d$$

The *direct relationship* between work and distance is illustrated in Figure 8-2. In practical terms, even a small force can do a lot of work if it is exerted over a long distance.

Using this equation, we can see that the units of work are equal to a force times a distance. In the metric system of units, in which force is measured in newtons and distance in meters, work is measured in newton-meters. This unit is given the special name **joule,** after the English scientist James Prescott Joule (1818–1889), one of the first people to understand the properties of energy. One *joule* (abbreviated 1 J) is defined as the amount of work done when you exert a force of 1 newton through a distance of 1 meter:

1 joule of Work = 1 newton of Force × 1 meter of Distance

EXAMPLE 8-1

Working Against Gravity

How much work do you do when you lift a 12-kilogram suitcase 0.75 meters off the ground (Figure 8-3)?

REASONING AND SOLUTION: We must first calculate the force needed to lift a 12-kilogram mass before we can determine the work done. This force is equal to the weight of the suitcase. From Chapter 5, we know that to lift a 10-kilogram mass against the acceleration of gravity (9.8 meters per second per second) requires a force given by:

$$\begin{aligned} \text{Force} &= \text{Mass} \times g \\ &= 12 \text{ kg} \times 9.8 \text{ m/s}^2 \\ &= 117.6 \text{ newtons} \end{aligned}$$

Then, from the equation for work,

$$\begin{aligned} \text{Work} &= \text{Force} \times \text{Distance} \\ &= 117.6 \text{ newtons} \times 0.75 \text{ meter} \\ &= 88.2 \text{ joules} \end{aligned}$$

In North America, work is often measured in the English system of units (see Appendix A), where force is recorded in pounds and distance in feet. Work is thus measured in a unit called the *foot-pound* (usually abbreviated ft-lb), which corresponds to the work done in lifting a weight of 1 pound 1 foot upward against the force of gravity. ●

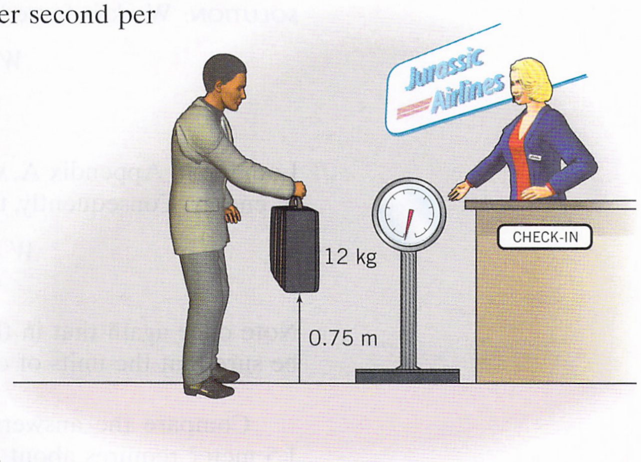


FIGURE 8-3. Lifting a suitcase off the ground requires you to do work against gravity.

Lifting Weights

EXAMPLE 8-2

It's not unusual for a professional athlete to be able to lift as much as 400 pounds (1780 newtons). Suppose that a football linebacker, lying on his back, pushes a 400-pound barbell from his chest to a position in which his arms are fully extended upward (Figure 8-4). (This action is called a "bench press" and gives rise to the sporting slang expression that an athlete can "press" a certain weight.) Estimate the amount of work he does in both SI and the English system.

REASONING: To calculate the work done, we need to multiply force times distance. The force in this problem is 400 pounds, but the distance isn't given. That means we have to estimate it. The athlete starts with the weight on his chest and keeps pushing until his arms are extended. This means that the distance over which the force is applied must be about the length of his arms. The length of a large man's arms is about 3 feet (in fact, the yard in the English system of units was originally defined as the distance from a man's nose to the end of his hand). So let's take the distance in the problem as 3 feet.

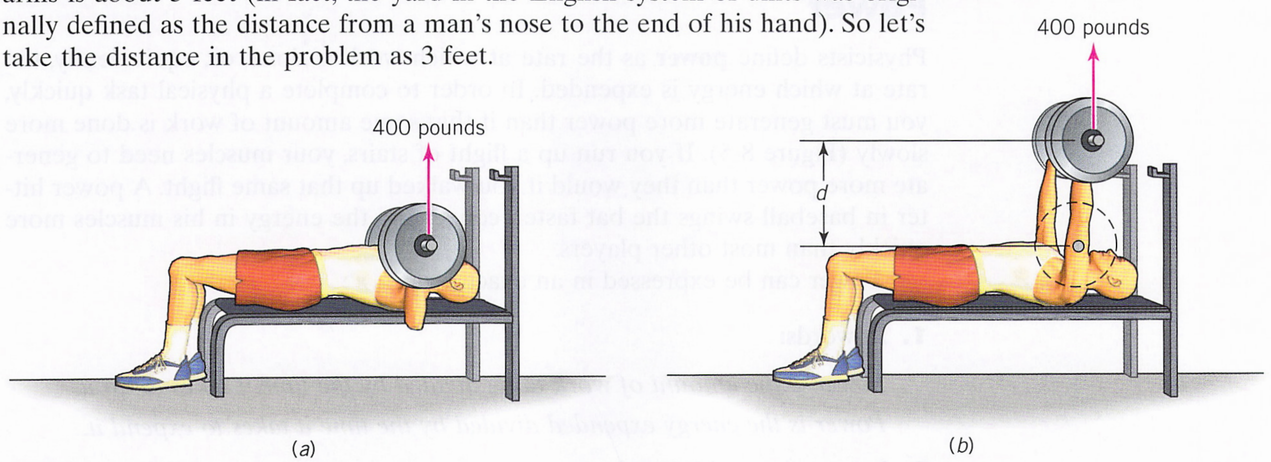


FIGURE 8-4. Athletes strengthen their muscles by working against gravity, for example by lifting weights. No pain, no gain!

SOLUTION: Work is force times distance, so

$$W = F \text{ (in pounds)} \times d \text{ (in feet)}$$
$$= 400 \text{ pounds} \times 3 \text{ feet}$$
$$= 1200 \text{ ft-lb}$$

Looking in Appendix A, we see that there are 1.356 joules for each foot-pound of energy. Consequently, this amount of work in SI is

$$W = 1200 \text{ ft-lb} \times 1.356 \text{ joules/ft-lb}$$
$$= 1627 \text{ joules}$$

Note once again that in this equation we can cancel units (in this case ft-lb) to be sure that the units of our answer are correct. ●

Compare the answers for Examples 8-1 and 8-2. Lifting a 12-kg suitcase 1.5 meter requires about 176 J of work; lifting a 400-lb barbell 3 feet (which is almost 1 meter) requires over 1600 J of work. Does this seem reasonable to you? (Note that 1 kilogram has a weight of about 2.2 pounds when $g = 9.8 \text{ m/s}^2$.)

Energy

Energy is defined as the ability to do work. If a system is capable of exerting a force over a distance, then it possesses energy. The amount of a system's energy, which can be recorded in joules or foot-pounds (the same units used for work), is a measure of how much work the system might do. When you run out of energy, you simply can't do any work.

Energy is one of the most useful concepts in all of science, from both theoretical and practical viewpoints. Determining the energy of a system is often the key step in analyzing its future behavior, and we're all familiar with the importance of energy in our modern industrial society. We examine details of energy in the rest of this chapter and again in later chapters. Examples of energy in common situations appear in Physics and Daily Life on p. 168.

Power

Physicists define **power** as the rate at which work is done, or, equivalently, the rate at which energy is expended. In order to complete a physical task quickly, you must generate more power than if that same amount of work is done more slowly (Figure 8-5). If you run up a flight of stairs, your muscles need to generate more power than they would if you walked up that same flight. A power hitter in baseball swings the bat faster, converting the energy in his muscles more quickly than most other players.

Power can be expressed in an exact form.

1. In words:

Power is the amount of work done divided by the time it takes to do it.

Power is the energy expended divided by the time it takes to expend it.

2. In equations with words:

$$\text{Power (in watts)} = \frac{\text{Work (in joules)}}{\text{Time (in seconds)}}$$

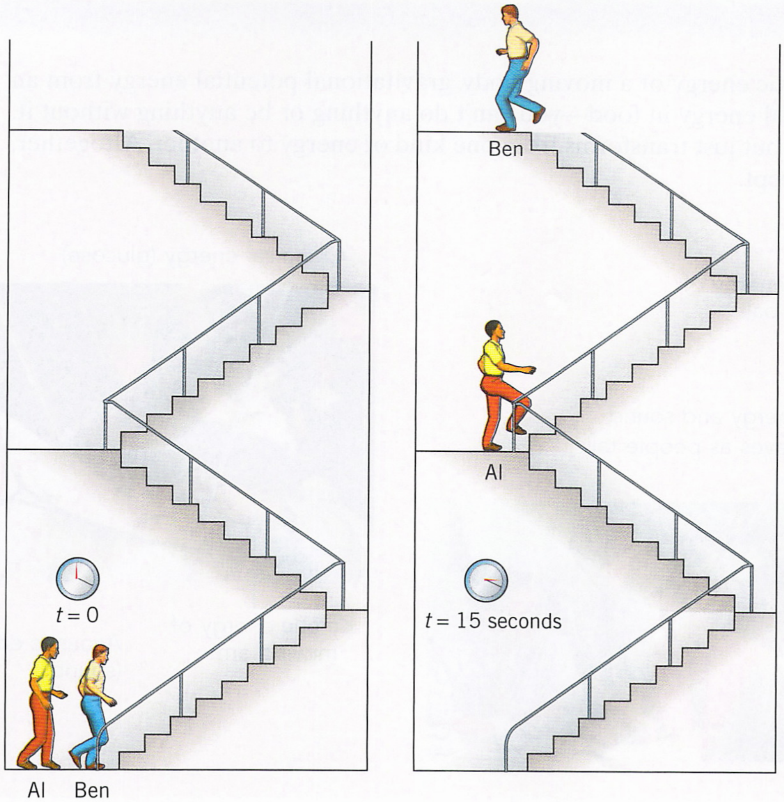


FIGURE 8-5. Power is the rate at which work is done, or, equivalently, the rate at which energy is expended. If Ben runs up two flights of stairs in the same time it takes Al to walk up one flight, then Ben expends twice as much power as Al.

or $$\text{Power (in watts)} = \frac{\text{Energy (in joules)}}{\text{Time (in seconds)}}$$

where the *watt* is the unit of power, as defined next.

3. In equations with symbols:

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

In the metric system power is measured in **watts,** a unit named after James Watt (1736–1819), a Scottish inventor who helped to develop the modern steam engine that powered the Industrial Revolution. The watt, a unit of measurement that you probably encounter every day, is defined as the expenditure of 1 joule of energy in 1 second:

$$\text{1 watt of Power} = \frac{\text{1 joule of Energy}}{\text{1 second of Time}}$$

When you change a lightbulb, for example, you look at the rating of the new bulb to see whether it's 60, 75, or 100 watts. This number provides a measure of the rate of energy that the lightbulb consumes when it is operating. Almost any electric hand tool or appliance in your home is also labeled with a power rating in watts. The unit of 1000 watts (corresponding to an expenditure of 1000 joules per second) is called a **kilowatt,** a commonly used measurement of electrical power. The English system, on the other hand, uses *horsepower,* which is defined as 550 foot-pounds per second (see Physics in the Making, page 169).

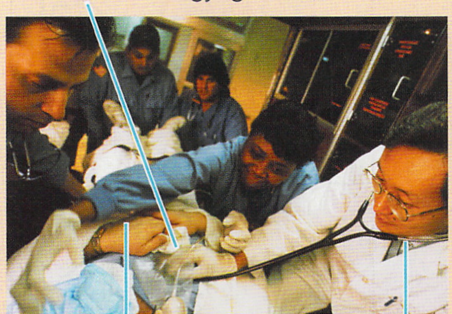
Physics and Daily Life—Energy

Energy is everywhere, whether kinetic energy of a moving body, gravitational potential energy from an object raised off the ground, chemical energy in food—you can't do anything or be anything without it. And it never disappears completely, but just transforms from one kind of energy to another. Altogether, a really useful and remarkable concept.

Kinetic energy of moving ball

Potential energy of body above ground

Energy and sound waves as people talk



Chemical energy (glucose)

Kinetic energy of moving arm

Acoustic energy (sound)

The equation defining power as energy divided by time may be rewritten as:

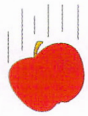
$$\text{Energy (in joules)} = \text{Power (in watts)} \times \text{Time (in seconds)}$$

This equation says that if you know how much power you are using and how long you are using it, you can calculate the total amount of energy expended. The electric company calculates your electric bill in this way. The equation tells us that if you use 100 watts of power for 1 hour (by having a lightbulb turned on, for example), you have expended 100 watt-hours of energy, or one-tenth of a kilowatt-hour. This measurement of energy used appears on your electric bill.

The terms and units related to work, energy, and power are summarized in Table 8-1.

TABLE 8-1 Important Terms Used in Energy

Quantity	Definition	Units
Force	Mass × Acceleration	Newtons
Work	Force × Distance	Joules
Energy	Ability to do work	Joules
Energy	Power × Time	Joules
Power	$\frac{\text{Work}}{\text{Time}} = \frac{\text{Energy}}{\text{Time}}$	Watts



Physics in the Making

James Watt and the Horsepower

James Watt devised the horsepower, a unit of power with a colorful history, so that he could sell his steam engines. Watt knew that the main use of his engines was in mines, where owners traditionally used horses to drive the pumps that removed water. The easiest way to promote his new engines was to tell the mining engineers how many horses each engine would replace. Consequently, he did a series of experiments to determine how much energy a horse could generate over a given amount of time. He found that, on average, a healthy horse can do 550 ft-lb of work every second over an average working day. Watt called this unit *horsepower* and rated his engines accordingly. We still use this unit (the engines of most cars and trucks are rated in horsepower), although these days we seldom build engines to replace horses. ●

TYPES OF ENERGY

Energy, the ability to do work, appears in many different kinds of physical systems, which give rise to many different kinds of energy. In this chapter we talk about only two of these categories—**kinetic energy,** which is energy associated with moving objects, and **gravitational potential energy,** which is a form of energy waiting to be released. We wait until Chapter 12, after we have discussed phenomena associated with heat, to talk about the many other categories of energy.

Kinetic Energy

Think about a cannonball flying through the air. When the iron ball hits a wooden target, the ball exerts a large force on the fibers in the wood, splintering them and pushing them apart, thereby creating a hole. The cannonball in flight clearly has the *ability* to do work because it is in motion. (If it were not in motion, it would remain on the ground and do no work at all.) This energy of motion is called *kinetic energy.* You can find countless examples of kinetic energy in the world around you. A swimming fish, a flying bird, a speeding car, a soaring Frisbee, a falling leaf, and a running child all have kinetic energy.

Our intuition tells us that two factors govern the amount of an object's kinetic energy. First, heavier objects have more energy than lighter ones: a bowling ball traveling 10 meters per second (a very fast sprint) carries a lot more kinetic energy than a ping-pong ball traveling at the same speed. In fact, kinetic energy is proportional to mass: double the mass and you double the kinetic energy (Figure 8-6*a* on page 170).

Second, the faster something is moving, the greater the force it is capable of exerting. A high-speed collision on the highway causes much more damage than a fender-bender in a parking lot. It turns out that an object's kinetic energy increases as the square of its velocity. A car moving 40 kilometers per hour has four times as much kinetic energy as one moving 20 km/h, while at 60 km/h a car carries nine times as much kinetic energy as at 20 km/h (Figure 8-6*b* on page 170). Thus, a modest increase in speed can cause a large increase in kinetic energy.

When a baseball breaks a window it demonstrates the existence of kinetic energy.

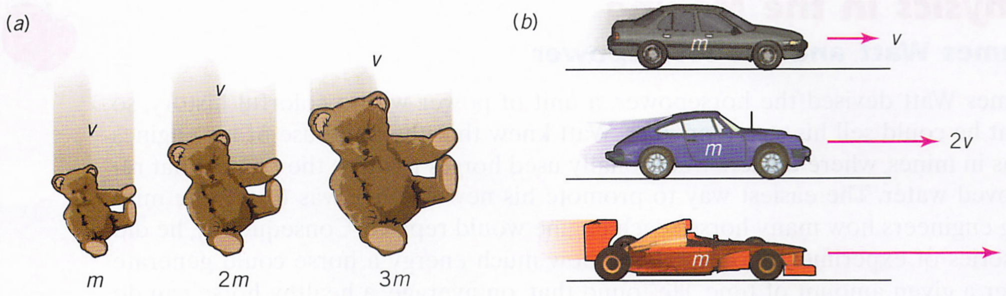


FIGURE 8-6. (*a*) Double the mass and you double the kinetic energy. (*b*) Double the velocity and you increase kinetic energy by a factor of four.

These ideas, presented as equations, lead to the following definition.

1. In words:

   Kinetic energy equals the mass of the moving object times the square of that object's velocity, multiplied by the constant $\frac{1}{2}$.

2. In an equation with words:

   $$\text{Kinetic energy (in joules)} = \frac{1}{2} \times \text{Mass (in kg)} \times [\text{Velocity (in m/s)}]^2$$

3. In an equation with symbols:

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

We won't discuss where the constant $\frac{1}{2}$ comes from, but it must be included for the formula to be correct. Some examples of kinetic energy are shown in Looking at Energy, on p. 171.

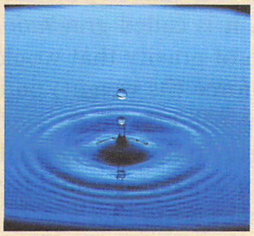
Kinetic Energy Versus Momentum Although kinetic energy and momentum are both properties of moving objects and although both depend on the mass and the velocity of that object, they are quite different quantities. To make this point clear, here are two important differences between them:

1. Momentum is a vector, while kinetic energy is a positive scalar. In a system with two moving objects—two moving billiard balls, for example—the momenta of the two objects can cancel each other either partially or completely if they travel in opposite directions. The energies of the two objects, however, always add to each other to give the total energy of the system.
2. Momentum grows linearly with velocity, but kinetic energy grows as the square of velocity. Double the velocity of one of those billiard balls and the momentum doubles, while the kinetic energy increases by a factor of four. This difference is underscored by Example 8-5 at the end of the chapter in which the bowling ball has a greater momentum, while the baseball carries more kinetic energy.

Looking at Energy

Raindrops are wet, but they don't hurt you when they fall on your head. That's because one raindrop has very little energy; it takes a lot of raindrops to hurt someone. Large hurricanes have such energy that they can bring down buildings and wash people away; they are among the most energetic natural phenomena on Earth. Most of our experience falls between these extremes, but physicists study interactions with far less and far more energy than is familiar to most people. For instance, the impact of a large meteor (10-km in diameter) colliding with Earth, as probably happened 65 million years ago, would have released enough energy to destroy most life on the planet at that time.

10^{-4} J



Raindrop, 0.0001 joule

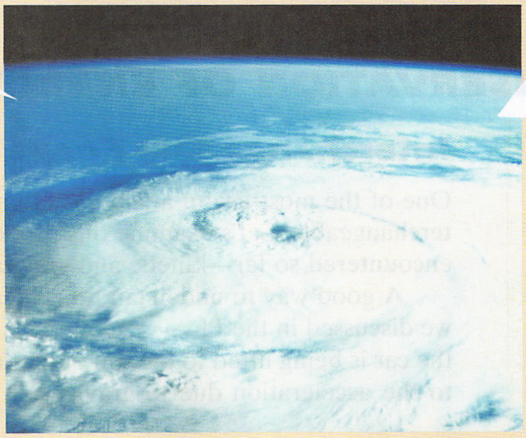
10^{-2} J

Pressing a computer key, 0.01 joule

10^{6} J

Riding in a car at 55 mph, 600,000 joules

10^{19} J

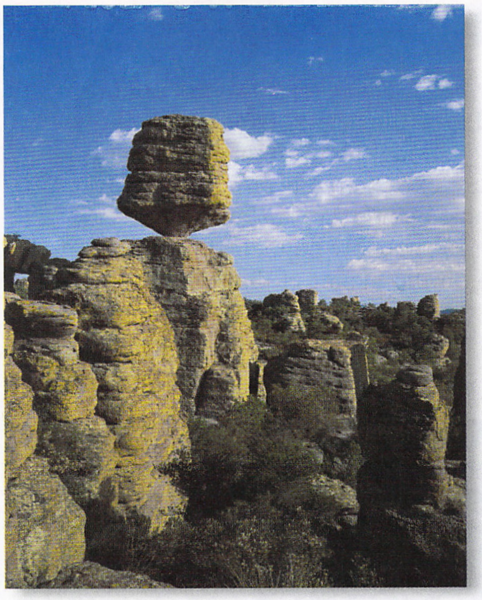


Typical hurricane, 10^{19} joules

10^{27} J

Impact of 10-km meteor striking Earth, 10^{27} joules

Potential Energy



A balancing rock doesn't do any work as long as it stays in place. If it starts to fall over, however, you don't want to get in its way.

Almost every mountain range in the country has a balancing rock, a boulder precariously perched on top of a hill so that it looks as if a little push would send it tumbling down the slope. If the balancing rock were to fall, it would acquire kinetic energy, and it would do work on anything it smashed into. This means that even though the balancing rock does no work while it is motionless, it still has the potential to do work. The boulder possesses energy just by virtue of having the potential of falling.

Energy that could result in the exertion of a force over a distance but is not doing so now is called "potential energy." In the case of the balancing rock, it is called *gravitational potential energy,* because it is the force of gravity that would cause the rock to move and exert its own force (its weight) on impact.

An object that has been lifted above the surface of the Earth possesses an amount of gravitational potential energy exactly equal to the total amount of work you would have to do to lift it from the ground to its present position.

1. In words:

The gravitational potential energy of any object equals its weight (the force of gravity exerted on the object) times its height above the ground.

2. In an equation with words:

$$\text{Gravitational potential energy (in joules)} = \text{Mass (in kg)} \times g \text{ (in m/s}^2) \times \text{Height (in m)}$$

where g is the acceleration due to gravity at the Earth's surface (see Chapter 3).

3. In an equation with symbols:

$$PE = mgh$$

In Example 8-1 we saw that if you lift a 12-kilogram suitcase 0.75 meters into the air, you do 88.2 joules of work and the suitcase acquires 88.2 joules of potential energy. This is the amount of work that would be done if the suitcase were allowed to fall, and it is the amount of gravitational potential energy stored in the elevated suitcase.

THE CONSERVATION OF ENERGY

Interchangeable Forms of Energy

One of the most useful attributes of energy is that all of its many forms are interchangeable. Let's examine this property for the two forms of energy we have encountered so far—kinetic and gravitational potential energies.

A good way to understand this idea is to think about the roller coaster ride we discussed in the Physics Around Us section at the start of this chapter. While the car is being lifted to the top of the track for the start of the run, a force equal to the acceleration due to gravity (g) times the mass (m) of the car (plus the

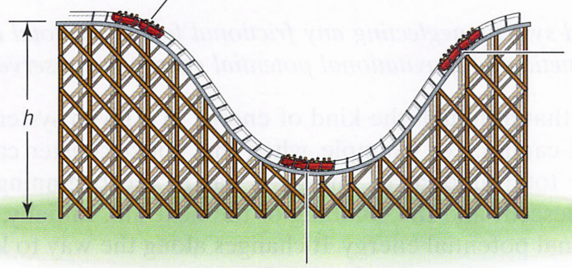


FIGURE 8-7. A roller coaster car has gravitational potential energy at the top of the hill and kinetic energy at the bottom of the hill. It has a mix of both kinds of energy at points in between.

passengers) is being applied over a distance h, where h is the height of the track. Thus, the work W done on the car is

$$W = mgh$$

This value is also the potential energy that the car has when it is resting at the top, ready to start down.

As the descent starts, two things happen: (1) the car starts to move and therefore acquires kinetic energy and (2) the car starts to lose height, so its potential energy begins to drop. By the time the car has reached the bottom of the first hill, it is at ground level, so its potential energy has been reduced to zero. At the same time, it is moving as fast as it is going to move, so its kinetic energy is at its maximum. On the way down, then, the potential energy has changed into kinetic energy—in other words, one form of energy has turned into another (Figure 8-7).

As the car starts up the second hill, this process goes on in reverse. As the car climbs, its potential energy increases while its kinetic energy drops. At the top of the second hill, when the car is momentarily stationary before its second swoop, all the kinetic energy it had at the bottom of the first hill has been converted back into potential energy. If we ignore losses due to friction (a subject we take up in Chapter 12), this back and forth transfer of energy between these two forms will go on forever.

We can summarize this result by saying that

Kinetic and gravitational potential energy are interchangeable.

This statement is actually a special case of a more general rule, a rule that states that *all* forms of energy are interchangeable.

The Principle of Energy Conservation

Physicists always look for constants in their efforts to describe a changing universe. Is the total number of atoms or electrons in the universe constant? Is the total amount of electric charge fixed? We have seen in Chapter 6 that any statement that says that a quantity in nature does not change—that it is conserved—is called a *conservation law*. We have already seen how the conservation laws relating to linear and angular momentum help us understand the behavior of physical systems. If anything, the conservation law for energy is even more important.

In terms of the forms of energy we have discussed so far, the **law of conservation of energy** states that

In a closed system, neglecting any frictional forces, the total amount of kinetic and gravitational potential energy is conserved.

This law tells us that although the kind of energy in a given system can change, the total amount cannot. For example, when that roller coaster car starts down the first hill, the total amount of energy it has at the beginning is still there throughout the descent and the climbing of the next hill. Initially, all of this energy is gravitational potential energy. It changes along the way to kinetic energy, but the total amount of these two forms of energy never changes.

If you ride in a roller coaster car, you're certainly aware of changing speed as the car drops down or climbs up, but there's no direct indication of how much potential energy or kinetic energy you have along the way. There is no joule meter you can use to measure the potential energy of a balancing rock or the kinetic energy of a falling one. The fact that you can't see energy directly doesn't change the fact that it exists and can affect you.

The concept of energy allows us to look at the world so that we can analyze it. In fact, it is probably the single most successful tool ever devised for explaining how nature works and predicting its future behavior. Physicists often try to look at situations in several ways, each way giving a different understanding of what is actually happening. You can look at a roller coaster car in terms of force and acceleration, in terms of impulse and changes in momentum, or in terms of potential and kinetic energy. However, if you want to calculate the car's speed at the bottom of the hill, conservation of energy is by far the most useful way to analyze the problem. This situation often proves to be the case, which is why we spend several chapters exploring how we can use the idea of energy to understand various natural processes. The most important thing about conservation of energy is that it has been used by physicists for over 200 years and has never failed to work. Clearly, then, conservation of energy embodies a fundamental truth about the physical world, as valid as any concept known to humanity.

Energy of a Falling Body

The fact that the sum of kinetic and potential energies must be conserved gives us an easy way to analyze the fall of an object from a height. At the beginning of the fall, just before the object is released, its energy is all potential. If it is at a height h above the ground, then we saw earlier that its energy is mgh joules. As the object falls, this potential energy is gradually converted to kinetic energy, until, just before it hits the ground, the conversion is complete. The energy is now all kinetic and is given by the expression $\frac{1}{2}mv^2$. From this fact, we can deduce some important facts about falling bodies.

1. In words:

The kinetic energy at the end of a fall is equal to the potential energy at the beginning.

2. In an equation with words:

Initial potential energy = Final kinetic energy

3. In an equation with symbols:

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

If we cancel the mass from both sides of the equation, we find

$$gh = \frac{1}{2}v^2 \qquad \text{or} \qquad v = \sqrt{2gh}$$

In other words, the speed of the object at the end of the fall is independent of the object's mass.

Develop Your Intuition: How To View an Object Falling

Many thinkers, including brilliant scientists such as Aristotle, thought that heavier objects should fall faster than light ones and should therefore have a higher velocity at the end of the fall. How would you explain our preceding result to someone who argues that the heavier object has more oomph at the end, and therefore has to be moving faster?

It is true that the heavier object has more kinetic energy when it reaches the end of the fall and therefore makes a bigger impact. It is also true, however, that the heavier object had more potential energy at the beginning of the fall because a greater force had to be applied to lift it a distance h. The lighter object had less potential energy at the start and has less kinetic energy at the end. The effects of mass simply cancel out, and both fall at the same speed.

THE WORK-ENERGY THEOREM

Let's think again about the example of the roller coaster in the Physics Around Us section. We have answered a lot of questions about how it works but one question remains: how did it acquire that potential energy in the first place? We know that when the roller coaster car was lifted up, a force was exerted over a distance to overcome the downward pull of gravity. In the language of physics, work was done. In Chapter 12 we see that work is actually the result of the expenditure of different sorts of energy. In the case of the roller coaster it was electrical energy driving a motor, while in the case of a barbell being lifted it was energy in the muscles of the weight lifter. In this context, the lifting of the car or a weight is just one more example of energy being changed from one form to another. If we confine our attention to kinetic and gravitational potential energy, however, as we have done so far, then we can make one more statement about work and energy:

> *The total potential and kinetic energy of an object in a given state is equal to the work that was done to bring the object to that state.*

This statement is known as the **work-energy theorem.**

In practical situations, it often turns out that what you need to look at are the changes in kinetic and potential energy. The work-energy theorem applied to changes in energy gives this statement:

The work done on an object is equal to the sum of the changes in kinetic and potential energy.

LOOKING DEEPER

Collisions

Collisions between objects are an extremely important and constantly recurring theme in physics. Much of what we know about the nucleus of the atom (Chapter 26) and about elementary particles (Chapter 27) comes from studies of particle collisions at the subatomic level. The concepts of conservation of momentum and conservation of energy provide a useful way of analyzing any collision process.

Consider two objects of mass m_1 and m_2, moving initially with velocities v_1 and v_2. Suppose they collide and we want to know what happens. To do this, we call the final velocities u_1 and u_2; our task is to determine these velocities (Figure 8-8*a*). Conservation of momentum tells us that:

$$\text{Initial momentum} = \text{Final momentum}$$

$$m_1v_1 - m_2v_2 = -m_1u_1 + m_2u_2$$

while conservation of energy tells us that if there are no gains or losses of energy in the collision:

$$\text{Initial energy} = \text{Final energy}$$

$$\frac{1}{2}m_1{v_1}^2 + \frac{1}{2}m_2{v_2}^2 = \frac{1}{2}m_1{u_1}^2 + \frac{1}{2}m_2{u_2}^2$$

Here we have two equations and two unknown quantities to find: u_1 and u_2. The rules of algebra tell us that we can always find solutions to this kind of problem. If we know the initial velocities of the two objects, be they billiard balls or subatomic particles, we can always find the final state of the system. This is a good example of the way in which the Newtonian clockwork universe operates (see Chapter 5).

Let's take a simple case, in which the objects are equal in mass (call it m) and are approaching each other with equal (but oppositely directed) velocities of magnitude v. In this case, conservation of momentum tells us that

$$m(v - v) = 0 = m\,(u_1 + u_2)$$

so that $$u_1 = u_2$$

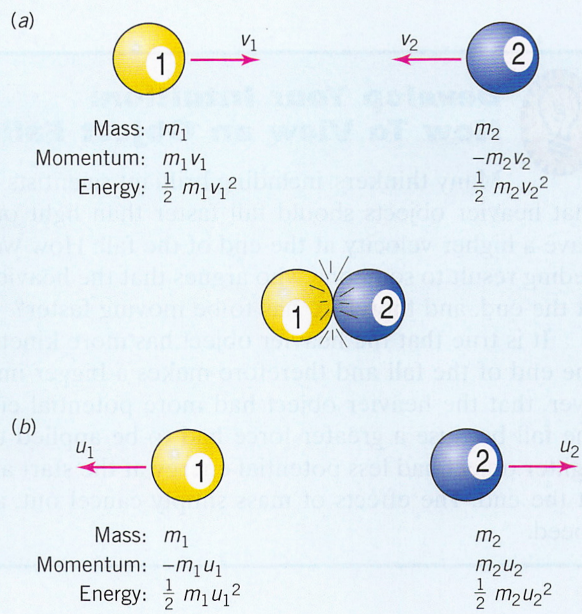


FIGURE 8-8. (*a*) A collision between two billiard balls is an example in which both momentum and energy are conserved. (*b*) If the two balls approach each other with the same speed before the collision, they rebound from each other with the same speed after the collision.

In other words, however fast the objects are moving after the collision, their velocities must be equal and opposite. Call the magnitude of the final velocity u. Then the energy equation tells us that if no energy is gained or lost in the collision,

$$\frac{1}{2}mv^2 + \frac{1}{2}mv^2 = \frac{1}{2}mu^2 + \frac{1}{2}mu^2$$

from which it follows that

$$u = v$$

In this collision, then, the two objects approach each other with the same speed, collide, and then move away from each other with the same speed that they had on approach (Figure 8-8*b*). If you think of two billiard balls colliding, you can see that this result is reasonable.

Develop Your Intuition: Adding Energy to the System

Consider a collision between billiard balls of equal mass that are traveling toward each other at equal speed v. At the moment of impact, an explosive cap on one ball explodes at the point of impact. How would the two equations in our analysis of collisions have to change for this situation?

All the forces associated with the cap are internal to the system, so they cannot affect the momentum of the system, which for our example remains zero. However, the cap does add energy to the system so that the energy equation now reads

$$\text{Initial energy} = \text{Final energy}$$

$$\frac{1}{2}mv^2 + \frac{1}{2}mv^2 + C = \frac{1}{2}mu^2 + \frac{1}{2}mu^2$$

where C is the amount of energy added to the system by the explosive cap. In this case, the final velocity, u, is higher than it would be without the cap, but the two balls still move away from each other at the same speed, back to back, so the final momentum is still zero.

Thinking More About

Simple Machines

The conversion back and forth from potential energy to kinetic energy is one of the most critical tasks of a technological society. To accomplish such energy conversions, humans have invented an extraordinary variety of *machines,* which are devices that change the direction or magnitude (or both) of an applied force. (This definition actually includes virtually all of the common tools, as well as more elaborate mechanical devices.) In the process, machines help us to apply a force over a distance—that is, to do work. In other words, machines help us convert between potential energy and kinetic energy in a wide variety of clever and useful ways. Three simple devices—the lever, the inclined plane, and the wheel and axle—lie at the heart of many familiar machines.

The lever Next time you watch a baseball game, notice how a power hitter can blast a baseball with one swing of the bat. The hitter achieves towering home runs by using a baseball bat—a beautiful example of the lever. A lever is simply a bar with a support (called the "fulcrum"), as we described in Chapter 7. Used properly, this simple device can increase an applied force. In a baseball swing, the batter's pivoting body serves as the fulcrum, while the extended arms act as the lever arm (Figure 8-9). Everyday examples of levers include a

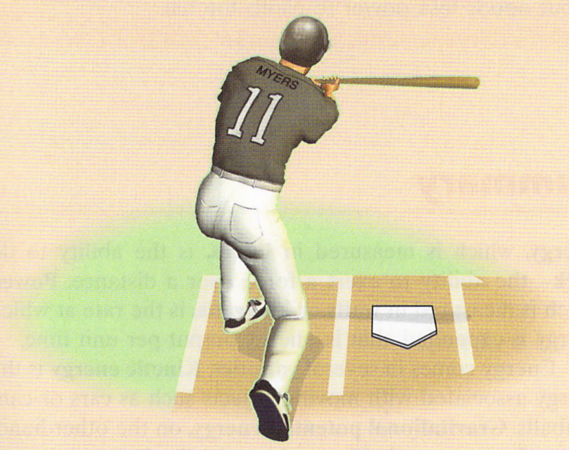


Figure 8-9. A view of a baseball hitter shows the lever effect of the pivoting body and extended arms.

claw hammer or crowbar, which can pry out a firmly lodged nail. The same principle comes into play when you use a tennis racquet or a sledgehammer, which can increase the applied force on a struck object. Staplers, nutcrackers, fishing poles, and bottle openers are just a few other examples of levers in our daily lives.

The inclined plane Have you ever driven over a high mountain pass? You probably noticed how the road winds back and forth in sharp switchbacks. A switchback road is a simple machine called an inclined plane, which exchanges an increased travel distance for less effort (less power). Variations on the inclined plane include ramps and screws. The exact same principle also occurs in the wedge, which is used to cut and split objects. Everyday examples of wedges include knives, scissors, axes, and your front teeth.

A mountain road with switchbacks is an example of an inclined plane. The car travels a longer distance but needs less power to climb the hill.

The wheel and axle The wheel and axle was one of the transforming technological inventions of human history. So common are wheels in our lives, that it's hard to imagine a society without this simple machine. The most obvious wheels in our lives are associated with vehicles—cars, bicycles, trains, and roller blades—in which wheels greatly reduce the friction of one object moving against another. But wheels appear in thousands of other devices, including clocks, fans, computer discs, ball bearings, gear trains, conveyor belts, and much more. In many of its everyday uses, including the steering wheel of your car, the capstan of a ship, pencil sharpeners, and valves, the wheel and axle may be thought of as a modification of a lever, in which the central axle acts like a fulcrum. To convince yourself of this idea, imagine common variants of water faucets, which can vary from simple levers to T-shaped handles or wheel-like valves.

Remarkably, many of the complex mechanical devices in our daily lives—cars, elevators, vending machines, and much more—are merely clever combinations of these three simple machines. Can you identify some of these simple machines in the devices you see around you? Some authorities classify the pulley, the wedge, and the screw as separate simple machines; try to see if you can recognize these elements as well. What do you think these simple machines all have in common?

Summary

Energy, which is measured in **joules,** is the ability to do **work**—the ability to exert a force over a distance. **Power,** which is measured in **watts** or **kilowatts,** is the rate at which energy is expended, that is, energy output per unit time.

Energy comes in several varieties. **Kinetic energy** is the energy associated with moving objects such as cars or cannonballs. **Gravitational potential energy,** on the other hand, is stored energy, ready for use; for example, the gravitational energy of dammed-up water. Energy can shift from one form to another, so that kinetic energy and gravitational potential energy are interchangeable. However, according to the **law of conservation of energy,** in a closed system, neglecting any frictional forces, the total amount of kinetic and gravitational potential energy is conserved.

The work needed to bring a system to a given state is equal to the sum of the kinetic and potential energies of the system. This statement, known as the **work-energy theorem,** relates the work done on a system to the total energy of that system.

Key Terms

energy The ability to do work. (p. 166)

gravitational potential energy The energy a body has by virtue of its position in a gravitational field. (p. 169)

joule The SI unit of work, corresponding to a force of 1 newton acting through 1 meter. (p. 167)

kilowatt The unit of 1000 watts (corresponding to an expenditure of 1000 joules per second). (p. 167)

kinetic energy The energy a body has by virtue of its motion. (p. 169)

law of conservation of energy The law that states that in a closed system the total amount of all forms of energy remains the same. (p. 174)

power The amount of work done divided by the time it takes to do it, or the energy expended divided by the time it takes to expend it. (p. 166)

watt The SI unit of power, defined as the expenditure of 1 joule of energy in 1 second. (p. 167)

work The product of the force exerted on an object times the distance over which it is exerted. (p. 163)

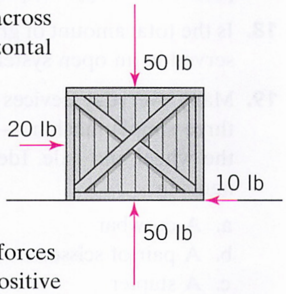
work-energy theorem The statement that the total potential and kinetic energy of an object in a given state is equal to the work that was done to bring the object to that state. (p. 175)

Review

1. What is the scientific definition of *work*? How does it differ from ordinary English use?
2. What is the definition of the *joule*? Why did scientists introduce this unit?
3. What is the difference between energy and power?
4. Is the kilowatt-hour a unit of energy or of power? How about kilowatt?
5. What is the difference between the watt and the horsepower?
6. What is the difference between the joule and the kilowatt-hour? Who uses which unit?
7. What is the definition of the *watt*? What is the relationship between the watt and the joule?
8. List some different kinds of energy. Explain how they differ from each other.
9. What factors determine the kinetic energy of a moving object?
10. Find something in your classroom or dorm room that possesses gravitational potential energy.
11. Look around your home and school. What objects in your everyday experience have the greatest potential energy?
12. What does it mean to say that different forms of energy are interchangeable?
13. What does it mean to say that energy is conserved?
14. What is the work-energy theorem? How does this theorem relate to the example of the roller coaster?
15. Give an example of the work-energy theorem in your home. Give another example at school.
16. What are the three simple machines? Give examples of each.
17. Identify some parts of an automobile and describe how they are used as simple machines.

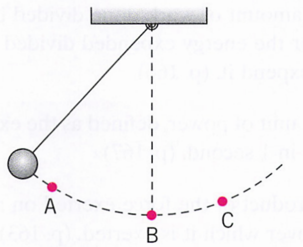
Questions

1. A 50-pound crate is pushed across the floor by a 20-pound horizontal force. Aside from the pushing force and gravity, there is also a 50-pound force exerted upward on the crate and a 10-pound frictional force, as shown in the figure. Which of these forces does no work? Which does positive work? Which does negative work?

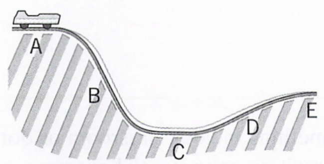


2. Two construction cranes are each able to lift a maximum load of 20,000 N to a height of 100 meters. However, one crane can lift that load in $\frac{1}{3}$ the time it takes the other. How much more power does the faster crane have?
3. As a freely falling object picks up downward speed, what happens to the power supplied by the gravitational force? Does it increase, decrease, or stay the same?
4. A pendulum swings left to right in the figure. At what locations in the pendulum's swing is the gravitational force

doing positive work? Negative work? No work? What is happening to the speed of the pendulum in each case?



5. Where in the roller coaster ride shown in the figure is the gravitational force doing positive work? Negative work? No work? What is happening to the speed of the car in each case?

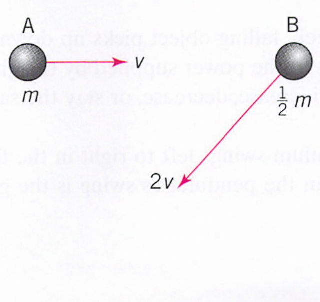


6. What kinds of energy are present in the following systems?
   a. Water behind a dam
   b. A swinging pendulum
   c. An apple on an apple tree
   d. The space shuttle in orbit

7. How do gravitational potential energy and kinetic energy shift in the following events?
   a. A baseball player hits a pop fly.
   b. A bungee jumper leaps off a high bridge.
   c. A meteor streaks down from space.
   d. An apple falls from a tree.

8. Identify which of the simple machines (the lever, the inclined plane, and the wheel and axle) are present in the following devices. (Note: Some devices incorporate more than one.)
   a. A toothbrush
   b. A fork
   c. A pizza cutter with a circular disk
   d. A saw
   e. A chisel
   f. A pencil sharpener

9. Which (if either) of the two objects shown has the greatest kinetic energy? Does it matter in which direction the objects are moving?



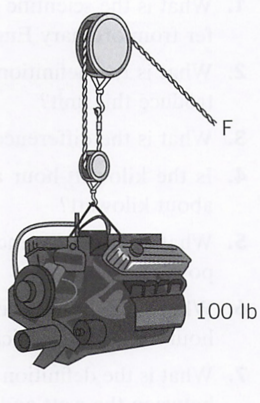
10. Where in the figure for Problem 4 does the pendulum have the greatest gravitational potential energy? Where does it have the greatest kinetic energy?

11. Where in the figure for Problem 5 does the roller coaster car have the greatest gravitational potential energy? Where does it have the greatest kinetic energy?

12. In the absence of air resistance, a falling rock gains kinetic energy and loses potential energy, with the total energy of the rock remaining constant. In the presence of air resistance, however, the rock eventually reaches terminal velocity. Now the kinetic energy is constant, but the potential energy continues to decrease as the rock falls toward the ground. What has happened to this missing energy?

13. According to the work-energy theorem, if work is done on an object, its potential and/or kinetic energy changes. Consider a car that accelerates from rest on a flat road. What force did the work that increased the car's kinetic energy?

14. Consider the block and tackle arrangement used to lift a 100-pound engine. What simple machine(s) is used in this arrangement? What force is necessary to hold up the engine? (*Hint:* How many ropes are actually supporting the weight?)



15. A 500-N crate needs to be lifted 1 meter vertically in order to get it into the back of a pickup truck. One option is to lift it directly up into the truck. Another option is to slide it up a frictionless inclined plane. Which method (if either) gives the crate more gravitational potential energy? What is the advantage of using the inclined plane?

16. List the several conservation laws that we have described thus far. In what ways are these laws similar?

17. Does the International Space Station have gravitational potential energy? Explain.

18. Is the total amount of gravitational and kinetic energy conserved in an open system? Why?

19. Many everyday devices incorporate more than one of the three simple machines—the lever, the inclined plane, and the wheel and axle. Identify the simple machine components in:
   a. A crowbar
   b. A pair of scissors
   c. A stapler
   d. A corkscrew

Problem-Solving Examples

EXAMPLE 8-3 Paying the Piper

A typical CD system uses 250 watts of electric power. If you play your system for three hours in an evening, how much energy do you use? If energy costs 8 cents a kilowatt-hour, how much do you owe the electric company?

REASONING AND SOLUTION: The given information consists of power and time, and you are asked to find an amount of energy. You can solve this problem by remembering the equation that relates energy used to amount of power:

$$\begin{aligned} \text{Energy} &= \text{Power} \times \text{Time} \\ &= 250 \text{ watts} \times 3 \text{ hours} \\ &= 750 \text{ watt-hours} \end{aligned}$$

Since 750 watts equals 0.75 kilowatt,

$$\text{Energy} = 0.75 \text{ kilowatt-hour}$$

The cost is

$$8 \text{ cents per kilowatt-hour} \times 0.75 \text{ kilowatt-hour} = 6 \text{ cents.}$$

EXAMPLE 8-4 Power Lifting

In Example 8-2 we talked about an athlete lifting a 400-pound weight. Suppose that, grunting and groaning, he lifts the barbell in 3 seconds. How much power is he expending in both English and SI units?

REASONING AND SOLUTION: Power is the work done divided by the time it takes to do it. Therefore, in the English system of units:

$$\begin{aligned} P \text{ (in ft-lb/s)} &= \frac{W \text{ (in foot-pounds)}}{t \text{ (in seconds)}} \\ &= \frac{1200 \text{ ft-lb}}{3 \text{ s}} \\ &= 400 \text{ ft-lb/s} \end{aligned}$$

But 1 horsepower is 550 ft-lb/s, so:

$$\begin{aligned} P \text{ (in hp)} &= \frac{400 \text{ ft-lb/s}}{550 \text{ ft-lb/s/hp}} \\ &= \frac{400}{550} \text{ hp} \\ &= 0.727 \text{ hp} \end{aligned}$$

In other words, for this very short period, the trained athlete is developing as much power as a small hand drill. In general, human beings can produce about $\frac{1}{4}$ hp over extended periods of time—a good deal less than a horse.

There are two ways to calculate the answer in SI units. One is to go to the table in Appendix A and find that one horsepower is equal to 745.7 watts. In this case

$$\begin{aligned} \text{Power (in watts)} &= 0.727 \text{ hp} \times 745.7 \text{ watts/hp} \\ &= 542.1 \text{ watts} \end{aligned}$$

The other way is to note from Example 8-2 that the athlete does 1627 joules of work in 3 seconds, so:

$$\begin{aligned} \text{Power (in watts)} &= \frac{1627 \text{ joules}}{3 \text{ seconds}} \\ &= 542.3 \text{ watts} \end{aligned}$$

The answers differ slightly due to rounding, but basically, they agree.

EXAMPLE 8-5 Bowling Ball Versus Baseball

What is the kinetic energy of a 4-kilogram (about 9-pound) bowling ball traveling down a bowling lane at 10 meters per second (22 miles per hour)? Compare this energy to that of a 250-gram (half-pound) baseball traveling 50 meters per second (110 miles per hour). Which object would hurt more if it hit you (that is, which object has the greater kinetic energy)?

REASONING AND SOLUTION: In this situation, the bowling ball has more mass but the baseball has more speed. The only way to really compare their energies is to substitute numbers into the equation for kinetic energy. For the 4-kg bowling ball traveling at 10 m/s,

$$\begin{aligned} \text{Energy (in joules)} &= \tfrac{1}{2} \times \text{Mass (in kg)} \times [\text{Velocity (in m/s)}]^2 \\ &= \tfrac{1}{2} \times 4 \text{ kg} \times (10 \text{ m/s})^2 \\ &= \tfrac{1}{2} \times 4 \text{ kg} \times 100 \text{ m}^2/\text{s}^2 \\ &= 200 \text{ kg-m}^2/\text{s}^2 \\ &= 200 \text{ joules} \end{aligned}$$

For the 250-gram baseball traveling at 50 meters per second,

$$\begin{aligned} \text{Energy (in joules)} &= \tfrac{1}{2} \times \text{Mass (in kg)} \times [\text{Velocity (in m/s)}]^2 \\ &= \tfrac{1}{2} \times 250 \text{ g} \times (50 \text{ m/s})^2 \end{aligned}$$

A gram is one-thousandth of a kilogram, so 250 g = 0.25 kg:

$$\begin{aligned}\text{Energy} &= \tfrac{1}{2} \times 0.25 \text{ kg} \times 2500 \text{ m}^2/\text{s}^2\\ &= 312.5 \text{ kg-m}^2/\text{s}^2\\ &= 312.5 \text{ joules}\end{aligned}$$

These results are summarized in Table 8-2. Even though the bowling ball is much more massive and has more momentum (mass × velocity) than a baseball, a hard-hit baseball carries more kinetic energy than a typical bowling ball because of its high velocity.

TABLE 8-2 Comparison of Kinetic Energy and Momentum

	Mass (kg)	Velocity (m/s)	Energy (J)	Momentum (kg-m/s)
Bowling ball	4	10	200	40
Baseball	0.25	50	312.5	12.5

EXAMPLE 8-6

Gravitational Potential Energy

1. What is the gravitational potential energy of a 4-kilogram bowling ball 1 meter above the ground?
2. How high would a 250-gram baseball have to be held above the ground to have the same potential energy?

REASONING AND SOLUTION:

1. Apply the equation for potential energy to the 4-kg bowling ball 1 meter above the ground:

$$\begin{aligned}PE &= mgh\\ &= 4 \text{ kg} \times 9.8 \text{ m/s}^2 \times 1 \text{ m}\\ &= 39.2 \text{ kg-m}^2/\text{s}^2\\ &= 39.2 \text{ joules}\end{aligned}$$

2. The second question asks for the height of a baseball in the case that:

$$(mgh)_{\text{bowling ball}} = (mgh)_{\text{baseball}}$$

Canceling g on both sides and inserting the known height of the bowling ball and the known masses of the two balls gives:

$$4 \text{ kg} \times 1 \text{ m} = 0.25 \text{ kg} \times h_{\text{baseball}}$$

Therefore,

$$\begin{aligned}h_{\text{baseball}} &= \frac{4 \text{ kg} \times 1 \text{ m}}{0.25 \text{ kg}}\\ &= 16 \text{ m}\end{aligned}$$

The baseball would have to be held 16 meters (more than 50 feet) above the ground to hold the same amount of gravitational potential energy as the bowling ball.

Problems

1. How much work against gravity do you do when you climb a flight of stairs 3 meters high? Compare this work to the energy consumed by a 60-watt lightbulb in an hour. How many flights of stairs would you have to climb to equal the work of the lightbulb?
2. Would you rather be hit by a 1-kilogram mass traveling 10 meters per second, or a 2-kilogram mass traveling 5 meters per second?
3. Compared to a car moving at 10 miles per hour, how much kinetic energy does that same car have when it moves at 20 miles per hour? At 30 miles per hour? At 60 miles per hour? What do these numbers suggest to you about the difficulty of stopping a car as its speed increases?
4. A small air compressor operates on a 1.5-horsepower electric motor for 8 hours a day. How much energy is consumed by the motor daily? If electricity costs 10 cents a kilowatt-hour, how much does it cost to run the compressor each day? (*Note:* 1 horsepower equals about 750 watts.)
5. The joule and the kilowatt-hour are both units of energy. How many joules are equal to 1 kilowatt-hour?
6. Zak, helping his mother rearrange the furniture in their living room, moves a 50-kg sofa 6 meters with a constant force of 20 newtons. Neglecting friction,
   a. What is the work done by Zak on the sofa?
   b. What is the average acceleration of the sofa?
7. Georgie was pulling her brother (20 kg) in a 10-kg sled with a constant force of 25 newtons for one block (100 meters).
   a. What is the work done by Georgie?
   b. How long would a 100-watt lightbulb have to glow to produce the same amount of energy expended by Georgie?
8. A woman weight lifter can lift a 150-lb weight from the floor to a stand 3.5 feet off the ground. What is the total work done by the woman in ft-lb and joules?
9. The stair stepper is a novel exercise machine that attempts to reproduce the work done against gravity by walking up stairs. With each step, Brad (60 kg) simulates stepping up a distance of 0.2 meters with this machine. If Brad exercises for 15 minutes a day with a stair stepper at a frequency of 60 steps per minute, what is the total work done by Brad each day?
10. Calculate the amount of energy produced in joules by a 100-watt lightbulb lit for 2.5 hours.

11. Normally the rate at which you expend energy during a brisk walk is 3.5 calories per minute. (A calorie is the common unit of food energy, equal to 0.239 joules.) How long (in minutes) do you have to walk in order to produce the same amount of energy as in a candy bar (approximately 280 calories)?
12. How long (in minutes) do you have to walk to produce the same amount of energy as a 100-watt lightbulb that is lit for 1 hour? Refer to Problem 11.
13. You throw a softball (250 g) straight up into the air. It reaches a maximum altitude of 15 meters and then returns to you. (Assume the ball departed from and returned to ground level.)
    a. What is the gravitational potential energy (in joules) of the softball at its highest position?
    b. What is the kinetic energy of the softball as soon as it leaves your hand? (Assume that there are no energy losses by the softball while it is in the air.)
    c. What is the kinetic energy of the softball when it returns to your hand?
    d. From the kinetic energy, calculate the velocity of the ball.
14. Sleeping normally consumes 1.3 calories of energy per minute for a typical 150-lb person. How many calories are expended during a good night's sleep of 8 hours?
15. You leave your 75-watt portable color TV on for 6 hours during the day and evening, and you do not pay attention to the cost of this electricity. If the dorm (or your parents) charged you for your electricity use and the cost was $0.10 per kW-hr, what would be your monthly (30-day) bill?
16. While skiing in Jackson, Wyoming, your friend Ben (65 kg) started his descent down the bunny run, 25 meters above the bottom of the run. If he started at rest and converted all of his gravitational potential energy into kinetic energy,
    a. What is Ben's kinetic energy at the bottom of the bunny run?
    b. What is his final velocity?
    c. Is this speed reasonable?
17. Lora (50 kg) is an expert skier. If she starts at 3 m/s at the top of the lynx run, which is 85 meters above the bottom, what is her final speed if she converts all her gravitational potential energy into kinetic energy? What is her final kinetic energy at the bottom of the ski run?
18. The Moon has a mass of 7.4×10^{22} kg and completes an orbit of radius 3.8×10^{8} m about every 28 days. The Earth has a mass of 6×10^{24} kg and completes an orbit of radius 1.5×10^{11} m every year.
    a. What is the speed of the Moon in its orbit? The speed of the Earth?
    b. What is the kinetic energy of the Moon in orbit? The kinetic energy of the Earth?
19. The current theory of the structure of the Earth, called plate tectonics, tells us that the continents are in constant motion. Right now, for example, the North American continent is moving at the rate of about 2 cm/year. Assume that the continent can be represented by a slab of rock 5000 km on a side and 30 km deep and that the rock has an average mass of 2800 kg/m^3.
    a. What is the mass of the continent?
    b. What is the kinetic energy of the continent?
    c. Compare this to the kinetic energy of a jogger of mass 70 kg running at a speed of 5 m/s.

Investigations

1. Look at your most recent electric bill and find the cost of 1 kilowatt-hour in your area.
    a. Look at the back of your CD player or another appliance and find the power rating in watts. How much does it cost for you to operate the device for 1 hour?
    b. If you leave a 100-watt lightbulb on all the time, how much will you pay in a year of electric bills?
    c. If you had to pay $10.00 for a high-efficiency bulb that provided the same light as the 100-watt bulb with only 10 watts of power, how much would you save per year if you used the bulb for 4 hours each day?

WWW Resources

See the *Physics Matters* home page at **www.wiley.com/college/trefil** for valuable web links.

1. **www.vast.org/vip/book/HOME.HTM** The physics of roller coasters online.
2. **www.physicsclassroom.com/Class/energy/energtoc.html** Two useful animated lessons on work, energy, and power from physicsclassroom.com (includes discussions of physics of skiing and roller coasters).
3. **www.nu.ac.za/physics/1M2002/Energy%20work%20and%20power.htm** A site from the University of Natal discussing energy content of food.
4. **www.bodybuilding.com/fun/becker2.htm** Presents the physics underlying weight lifting, including gravity, friction, mechanical advantage, work, and power.