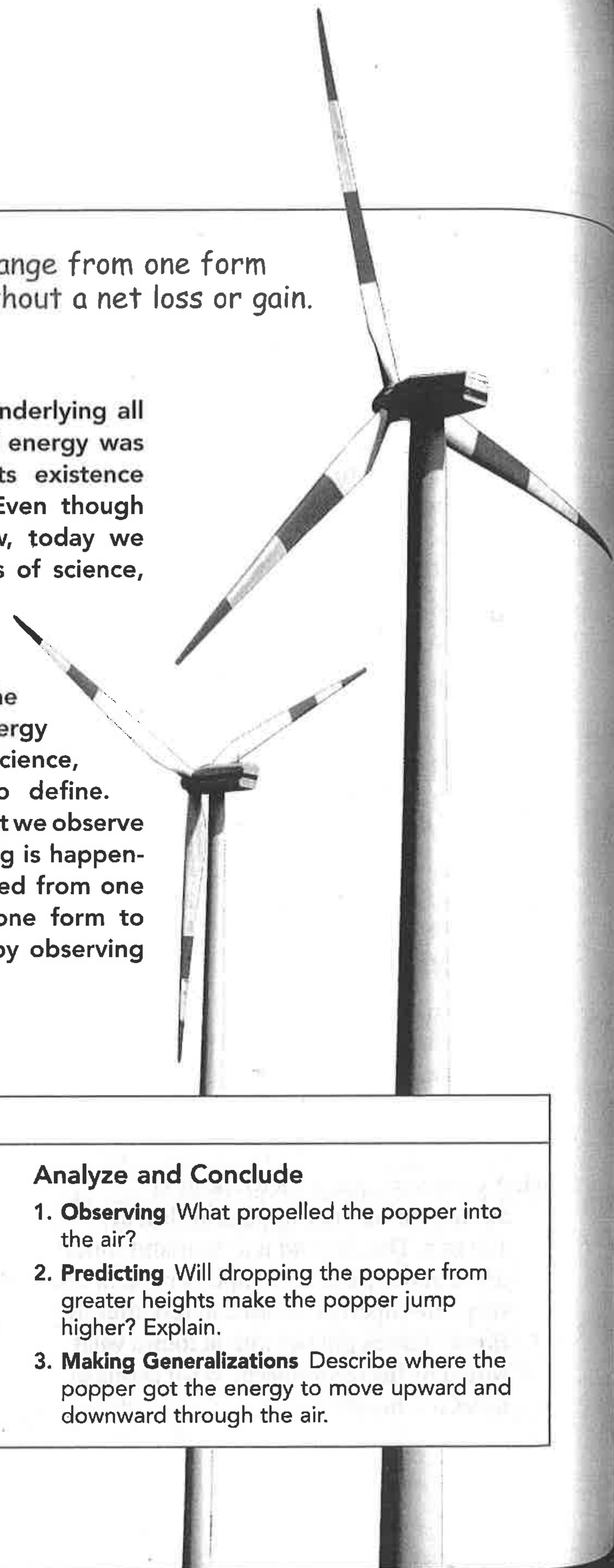
9 ENERGY

THE BIG IDEA Energy can change from one form to another without a net loss or gain.



Energy is the most central concept underlying all of science. Surprisingly, the idea of energy was unknown to Isaac Newton, and its existence was still being debated in the 1850s. Even though the concept of energy is relatively new, today we find it ingrained not only in all branches of science, but in nearly every aspect of human society. We are all quite familiar with energy. Energy comes to us from the sun in the form of sunlight, it is in the food we eat, and it sustains life. Energy may be the most familiar concept in science, yet it is one of the most difficult to define. Persons, places, and things have energy, but we observe only the effects of energy when something is happening—only when energy is being transferred from one place to another or transformed from one form to another. We begin our study of energy by observing a related concept, *work*.

discover!

Where Does a Popper Toy Get Its Energy?

1. Turn a popper (slice of a hollow rubber ball) inside out and place it on a table or floor. Observe what happens to the popper toy.
2. Once again compress the popper and drop it onto a table or floor. Observe what happens to the popper.

Analyze and Conclude

1. **Observing** What propelled the popper into the air?
2. **Predicting** Will dropping the popper from greater heights make the popper jump higher? Explain.
3. **Making Generalizations** Describe where the popper got the energy to move upward and downward through the air.

9.1 Work

The previous chapter showed that the change in an object's motion is related to both force and how long the force acts. "How long" meant time. Remember, the quantity *force* × *time* is called *impulse*. But "how long" need not always mean time. It can mean distance also. When we consider the quantity *force* × *distance*, we are talking about the concept of work. **Work** is the product of the net force on an object and the distance through which the object is moved.

We do work when we lift a load against Earth's gravity. The heavier the load or the higher we lift it, the more work we do. **Work is done when a force acts on an object and the object moves in the direction of the force.**

Let's look at the simplest case, in which the force is constant and the motion takes place in a straight line in the direction of the force. Then the work done on an object by an applied force is the product of the force and the distance through which the object is moved.[9.1]

$$\text{work} = \text{net force} \times \text{distance}$$

In equation form,

$$W = Fd$$

If we lift two loads up one story, we do twice as much work as we would in lifting one load the same distance, because the *force* needed to lift twice the weight is twice as great. Similarly, if we lift one load two stories instead of one story, we do twice as much work because the *distance* is twice as great.

Notice that the definition of work involves both a force *and* a distance. The weight lifter in Figure 9.1 is holding a barbell weighing 1000 N over his head. He may get really tired holding it, but if the barbell is not moved by the force he exerts, he does no work on the barbell. Work may be done on the muscles by stretching and squeezing them, which is force times distance on a biological scale, but this work is not done on the barbell. Lifting the barbell, however, is a different story. When the weight lifter raises the barbell from the floor, he is doing work on it.

Work generally falls into two categories. One of these is the work done against another force. When an archer stretches her bowstring, she is doing work against the elastic forces of the bow. Similarly, when the ram of a pile driver is raised, work is required to raise the ram against the force of gravity. When you do push-ups, you do work against your own weight. You do work on something when you force it to move against the influence of an opposing force—often friction.

think!

Suppose that you apply a 60-N horizontal force to a 32-kg package, which pushes it 4 meters across a mailroom floor. How much work do you do on the package?
Answer: 9.1

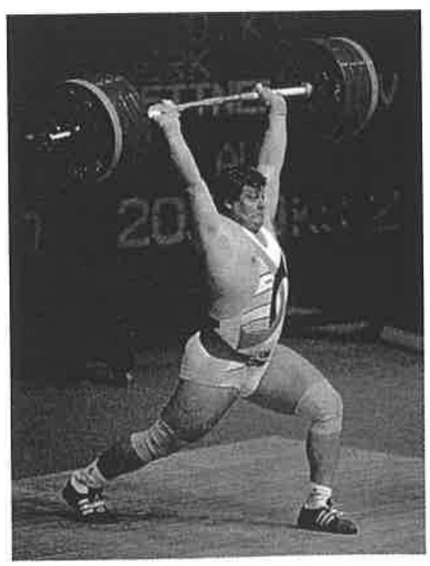
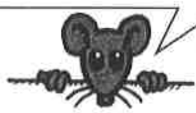


FIGURE 9.1 ▲
Work is done in lifting the barbell but not in holding it steady. If the barbell could be lifted twice as high, the weight lifter would have to do twice as much work.

The physics of a weightlifter holding a stationary barbell overhead is no different than the physics of a table supporting a barbell's weight. No net force acts on the barbell, no work is done on it, and no change in its energy occurs.



The other category of work is work done to change the speed of an object. This kind of work is done in bringing an automobile up to speed or in slowing it down. In both categories, work involves a transfer of energy between something and its surroundings.

The unit of measurement for work combines a unit of force, N, with a unit of distance, m. The resulting unit of work is the newton-meter (N·m), also called the **joule** (rhymes with cool) in honor of James Joule. One joule (J) of work is done when a force of 1 N is exerted over a distance of 1 m, as in lifting an apple over your head. For larger values, we speak of kilojoules (kJ)—thousands of joules—or megajoules (MJ)—millions of joules. The weight lifter in Figure 9.1 does work on the order of kilojoules. To stop a loaded truck going at 100 km/h takes megajoules of work.

CONCEPT CHECK **When is work done on an object?**

9.2 Power

The definition of work says nothing about how long it takes to do the work. When carrying a load up some stairs, you do the same amount of work whether you walk or run up the stairs. So why are you more tired after running upstairs in a few seconds than after walking upstairs in a few minutes? To understand this difference, we need to talk about how fast the work is done, or power. **Power** is the rate at which work is done. **Power equals the amount of work done divided by the time interval during which the work is done.**

$$\text{power} = \frac{\text{work done}}{\text{time interval}}$$

A high-power engine does work rapidly. An automobile engine that delivers twice the power of another automobile engine does not necessarily produce twice as much work or go twice as fast as the less powerful engine. Twice the power means the engine can do twice the work in the same amount of time or the same amount of work in half the time. A powerful engine can get an automobile up to a given speed in less time than a less powerful engine can.

The unit of power is the joule per second, also known as the **watt,** in honor of James Watt, the eighteenth-century developer of the steam engine. One watt (W) of power is expended when one joule of work is done in one second. One kilowatt (kW) equals 1000 watts. One megawatt (MW) equals one million watts. The space shuttle in Figure 9.2 uses 33,000 MW of power.

FIGURE 9.2 ▼
The three main engines of the space shuttle can develop 33,000 MW of power when fuel is burned at the enormous rate of 3400 kg/s. This is like emptying an average-size swimming pool in 20 seconds!

In the United States, we customarily rate engines in units of horsepower and electricity in kilowatts, but either may be used. In the metric system of units, automobiles are rated in kilowatts. One horsepower (hp) is the same as 0.75 kW, so an engine rated at 134 hp is a 100-kW engine.

CONCEPT CHECK How can you calculate power?

think!

If a forklift is replaced with a new forklift that has twice the power, how much greater a load can it lift in the same amount of time? If it lifts the same load, how much faster can it operate? *Answer: 9.2*

9.3 Mechanical Energy

When work is done by an archer in drawing back a bowstring, the bent bow acquires the ability to do work on the arrow. When work is done to stretch a rubber band, the rubber band acquires the ability to do work on an object when it is released. When work is done to wind a spring mechanism, the spring acquires the ability to do work on various gears to run a clock, ring a bell, or sound an alarm.

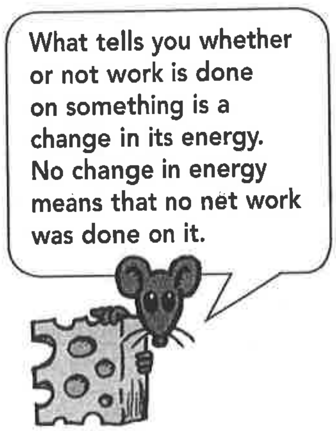
In each case, something has been acquired that enables the object to do work. It may be in the form of a compression of atoms in the material of an object; a physical separation of attracting bodies; or a rearrangement of electric charges in the molecules of a substance. The property of an object or system that enables it to do work is **energy.** [9.3] Like work, energy is measured in joules. It appears in many forms that will be discussed in the following chapters. For now we will focus on mechanical energy. **Mechanical energy** is the energy due to the position of something or the movement of something. **The two forms of mechanical energy are kinetic energy and potential energy.**

CONCEPT CHECK What are the two forms of mechanical energy?

discover!

What Happens When You Do Work on Sand?

1. Pour a handful of dry sand into a can.
2. Measure the temperature of the sand with a thermometer.
3. Remove the thermometer and cover the can.
4. Shake the can vigorously for a minute or so. Now remove the cover and measure the temperature of the sand again.
5. Describe what happened to the temperature of the sand after you shook it.
6. **Think** How can you explain the change in temperature of the sand in terms of work and energy?



9.4 Potential Energy

An object may store energy by virtue of its position. Energy that is stored and held in readiness is called **potential energy** (PE) because in the stored state it has the potential for doing work. ✓ **Three examples of potential energy are elastic potential energy, chemical energy, and gravitational potential energy.**

Elastic Potential Energy A stretched or compressed spring, for example, has a potential for doing work. This type of potential energy is *elastic potential energy.* When a bow is drawn back, energy is stored in the bow. The bow can do work on the arrow. A stretched rubber band has potential energy because of its position. If the rubber band is part of a slingshot, it is also capable of doing work.

Chemical Energy The chemical energy in fuels is also potential energy. It is actually energy of position at the submicroscopic level. This energy is available when the positions of electric charges within and between molecules are altered, that is, when a chemical change takes place. Any substance that can do work through chemical reactions possesses chemical energy. Potential energy is found in fossil fuels, electric batteries, and the food we eat.

Gravitational Potential Energy Work is required to elevate objects against Earth's gravity. The potential energy due to elevated positions is *gravitational potential energy.* Water in an elevated reservoir and the raised ram of a pile driver have gravitational potential energy.

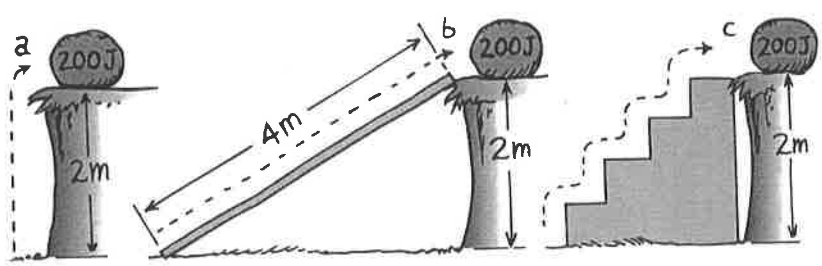


FIGURE 9.3 ▲
The potential energy of the 100-N boulder with respect to the ground below is 200 J in each case because the work done in elevating it 2 m is the same whether the boulder is **a.** lifted with 100 N of force, **b.** pushed up the 4-m incline with 50 N of force, or **c.** lifted with 100 N of force up each 0.5-m stair. No work is done in moving it horizontally, neglecting friction.

The amount of gravitational potential energy possessed by an elevated object is equal to the work done against gravity in lifting it. The work done equals the force required to move it upward times the vertical distance it is moved (remember $W = Fd$). The upward force required while moving at constant velocity is equal to the weight, mg, of the object, so the work done in lifting it through a height h is the product mgh.

$$\text{gravitational potential energy} = \text{weight} \times \text{height}$$

$$PE = mgh$$

Note that the height is the distance above some arbitrarily chosen reference level, such as the ground or the floor of a building. The gravitational potential energy, mgh, is relative to that level and depends only on mg and h. For example, if you're in a third-story classroom and a ball rests on the floor, you can say the ball is at height 0. Lift it and it has positive PE relative to the floor. Toss it out the window and it has negative PE relative to the floor. We can see in Figure 9.3 that the potential energy of the boulder at the top of the ledge does not depend on the path taken to get it there.

Hydroelectric power stations make use of gravitational potential energy. When a need for power exists, water from an upper reservoir flows through a long tunnel to an electric generator. Gravitational potential energy of the water is converted to electrical energy. Most of this energy is delivered to consumers during daylight hours. A few power stations *buy* electricity at night, when there is much less demand. They use this electricity to pump water from a lower reservoir back up to the upper reservoir. This process, called *pumped storage*, is practical when the cost of electricity is less at night. Then electrical energy is transformed to gravitational potential energy. Although the pumped storage system doesn't generate any overall net energy, it helps to smooth out differences between energy demand and supply.

CONCEPT CHECK **Name three examples of potential energy.**

think!

You lift a 100-N boulder 1 m.

a. How much work is done on the boulder?

b. What power is expended if you lift the boulder in a time of 2 s?

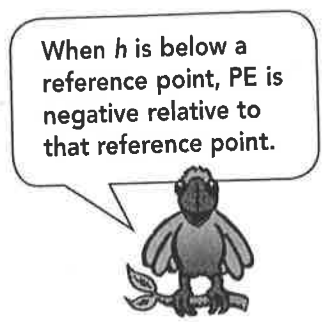
c. What is the gravitational potential energy of the boulder in the lifted position? *Answer: 9.4*

Go Online SCI LINKS NSTA

For: Links on potential energy

Visit: www.SciLinks.org

Web Code: csn – 0904



Refer to Note 9.5 in Appendix G for the derivation of the equation $W = \Delta KE$.

9.5 Kinetic Energy

Push on an object and you can set it in motion. If an object is moving, then it is capable of doing work. It has energy of motion, or **kinetic energy** (KE). The kinetic energy of an object depends on the mass of the object as well as its speed. It is equal to half the mass multiplied by the square of the speed.

$$\text{kinetic energy} = \frac{1}{2}\text{mass} \times \text{speed}^2$$

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

When you throw a ball, you do work on it to give it speed as it leaves your hand. The moving ball can then hit something and push it, doing work on what it hits. **The kinetic energy of a moving object is equal to the work required to bring it to its speed from rest, or the work the object can do while being brought to rest.** 9.5

$$\text{net force} \times \text{distance} = \text{kinetic energy}$$

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

Note that the speed is squared, so if the speed of an object is doubled, its kinetic energy is quadrupled ($2^2 = 4$). Consequently, it takes four times the work to double the speed. Also, an object moving twice as fast takes four times as much work to stop. Whenever work is done, energy changes.

CONCEPT CHECK: How are work and the kinetic energy of a moving object related?

Physics of Sports

The Sweet Spot

The sweet spot of a softball bat or a tennis racquet is the place where the ball's impact produces minimum vibrations in the racquet or bat. Strike a ball at the sweet spot and it goes faster and farther. Strike a ball in another part of the bat or racquet, and vibrations can occur that sting your hand! From an energy point of view, there is energy in the vibrations of the bat or racquet. There is energy in the ball after being struck. Energy that is not in vibrations is energy available to the ball. Do you see why a ball will go faster and farther when struck at the sweet spot?