As this bungee jumper falls, he gains kinetic energy, the energy of motion. Where does this energy come from? And where does it go as he slows at the bottom of his fall?

Forms of Energy

A principal goal of this chapter is to learn about several important forms of energy.

Kinetic energy is the energy of motion. This heavy, fast-moving rhinoceros has lots of kinetic energy.

These passengers gain **potential energy,** the energy of position, as they ride up the escalator.

The **thermal energy** of this red-hot horseshoe is associated with the microscopic motion of its molecules.

Transferring Energy

Energy can be *transferred* into a system by pushing on it, a process called **work.**

The bobsledders do work on the sled, *transferring* energy to it and causing it to speed up.

Transforming Energy

Energy of one kind can change into energy of a different kind. These **energy transformations** are what make the world an interesting place.

As this race car skids to a stop, its kinetic energy is being *transformed* into thermal energy, making the tires hot enough to smoke.

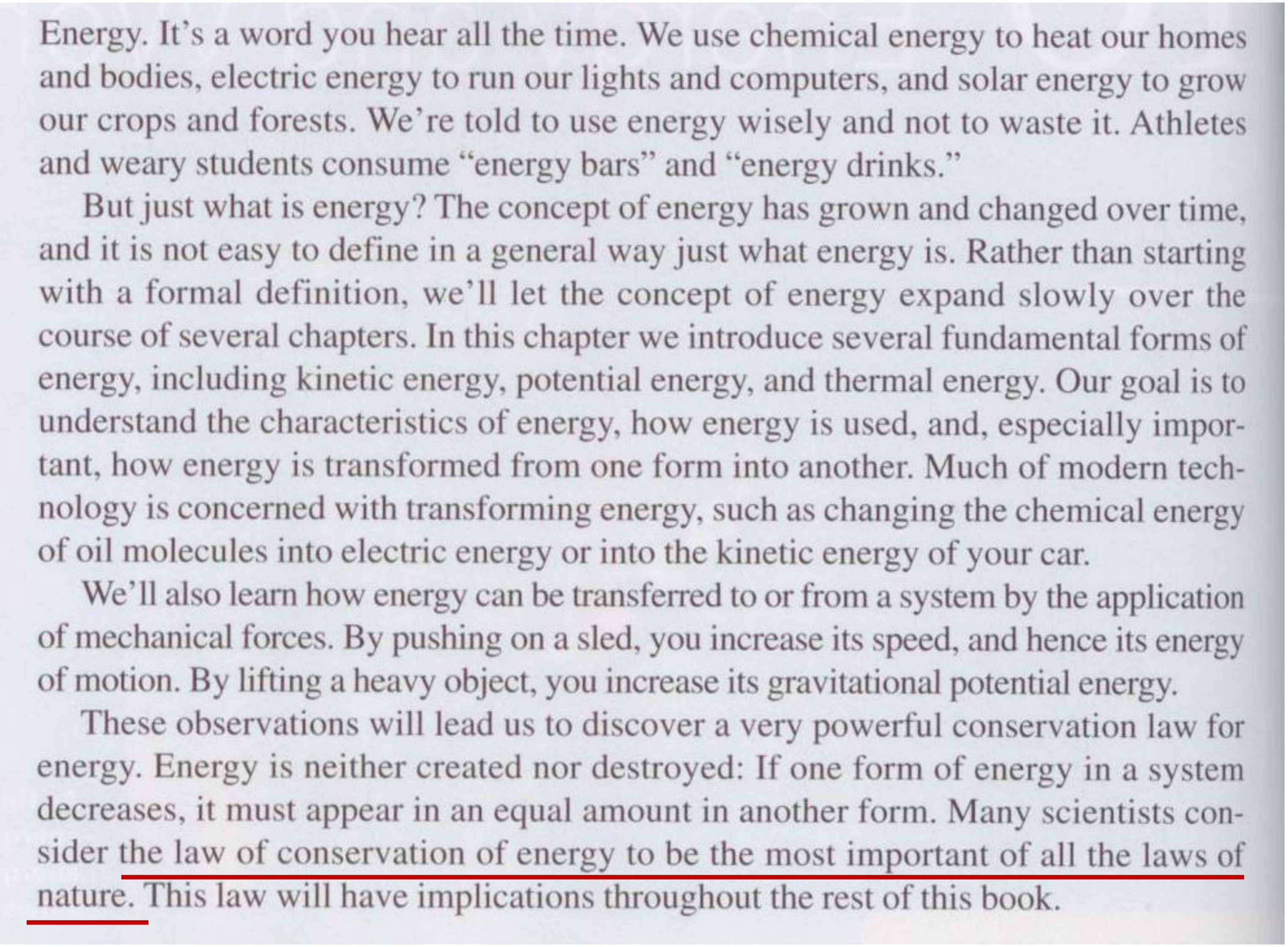
The Law of Conservation of Energy

One of the most fundamental laws of physics, the **law of conservation of energy** states that the total energy of an isolated system is a constant.

Power

We're very often interested in **power,** the *rate* at which energy is transformed from one kind into another.

As they climb, this truck and these jets both transform the chemical energy of their fuel into potential energy. But the jet engines transform energy at a rate 70 times that of the truck's engine—their *power* is much greater.



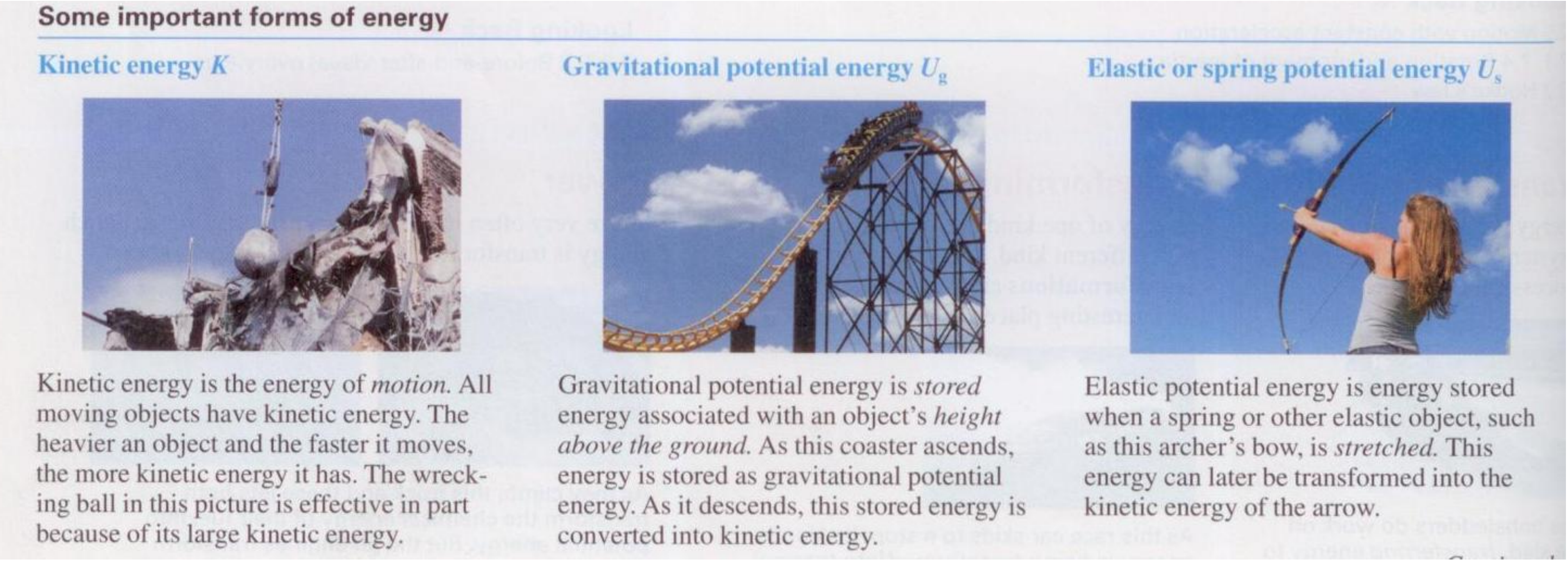
Energy. It's a word you hear all the time. We use chemical energy to heat our homes and bodies, electric energy to run our lights and computers, and solar energy to grow our crops and forests. We're told to use energy wisely and not to waste it. Athletes and weary students consume "energy bars" and "energy drinks."

But just what is energy? The concept of energy has grown and changed over time, and it is not easy to define in a general way just what energy is. Rather than starting with a formal definition, we'll let the concept of energy expand slowly over the course of several chapters. In this chapter we introduce several fundamental forms of energy, including kinetic energy, potential energy, and thermal energy. Our goal is to understand the characteristics of energy, how energy is used, and, especially important, how energy is transformed from one form into another. Much of modern technology is concerned with transforming energy, such as changing the chemical energy of oil molecules into electric energy or into the kinetic energy of your car.

We'll also learn how energy can be transferred to or from a system by the application of mechanical forces. By pushing on a sled, you increase its speed, and hence its energy of motion. By lifting a heavy object, you increase its gravitational potential energy.

These observations will lead us to discover a very powerful conservation law for energy. Energy is neither created nor destroyed: If one form of energy in a system decreases, it must appear in an equal amount in another form. Many scientists consider the law of conservation of energy to be the most important of all the laws of nature. This law will have implications throughout the rest of this book.

Forms of Energy



Some important forms of energy

Kinetic energy K

Kinetic energy is the energy of *motion.* All moving objects have kinetic energy. The heavier an object and the faster it moves, the more kinetic energy it has. The wrecking ball in this picture is effective in part because of its large kinetic energy.

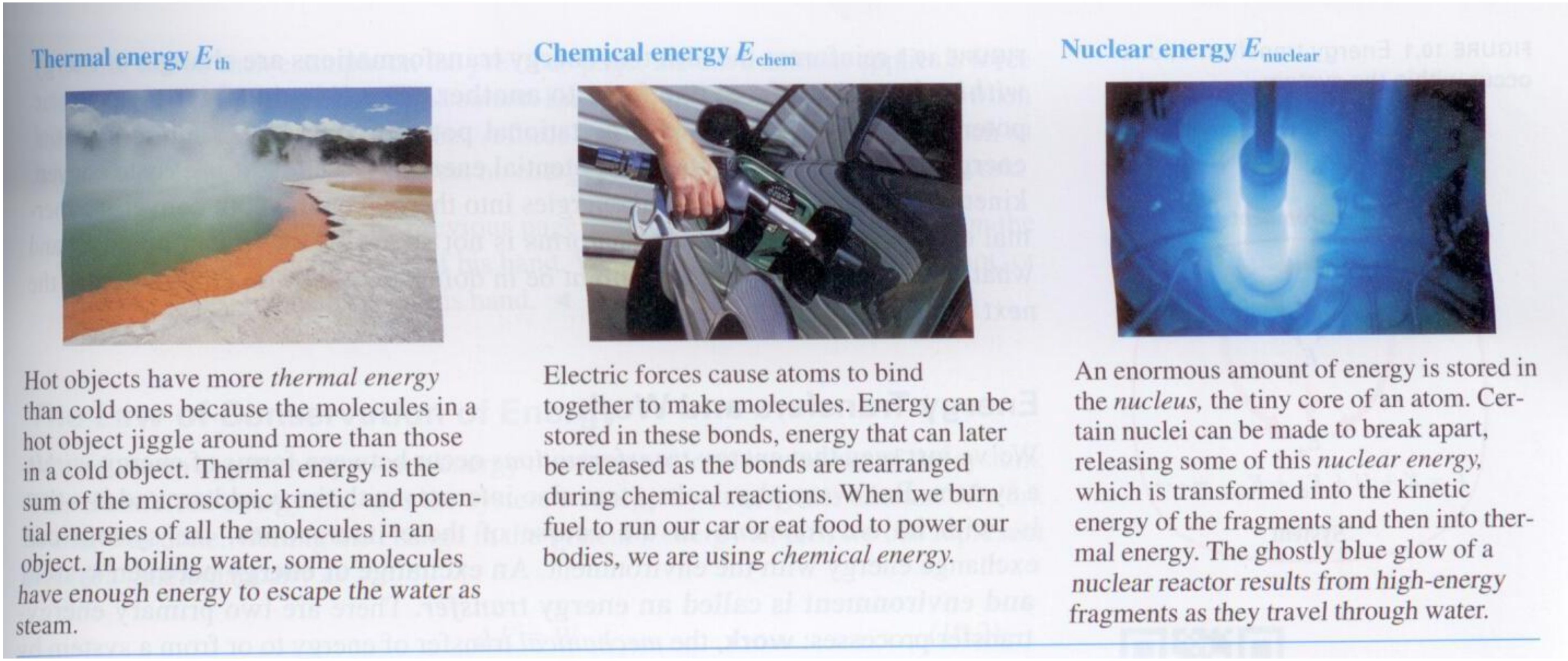
Gravitational potential energy U_g

Gravitational potential energy is *stored* energy associated with an object's *height above the ground.* As this coaster ascends, energy is stored as gravitational potential energy. As it descends, this stored energy is converted into kinetic energy.

Elastic or spring potential energy U_s

Elastic potential energy is energy stored when a spring or other elastic object, such as this archer's bow, is *stretched.* This energy can later be transformed into the kinetic energy of the arrow.

Forms of Energy



Thermal energy E_{th}

Hot objects have more *thermal energy* than cold ones because the molecules in a hot object jiggle around more than those in a cold object. Thermal energy is the sum of the microscopic kinetic and potential energies of all the molecules in an object. In boiling water, some molecules have enough energy to escape the water as steam.

Chemical energy E_{chem}

Electric forces cause atoms to bind together to make molecules. Energy can be stored in these bonds, energy that can later be released as the bonds are rearranged during chemical reactions. When we burn fuel to run our car or eat food to power our bodies, we are using *chemical energy.*

Nuclear energy E_{nuclear}

An enormous amount of energy is stored in the *nucleus,* the tiny core of an atom. Certain nuclei can be made to break apart, releasing some of this *nuclear energy,* which is transformed into the kinetic energy of the fragments and then into thermal energy. The ghostly blue glow of a nuclear reactor results from high-energy fragments as they travel through water.

Energy Transformations

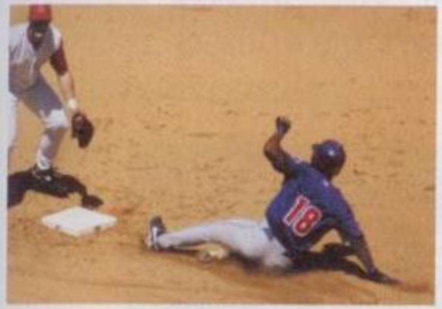
We've seen that all systems contain energy in many different forms. But if the amounts of each form of energy never changed, the world would be a very dull place. What makes the world interesting is that **energy of one kind can be *transformed* into energy of another kind.** The gravitational potential energy of the roller coaster at the top of the track is rapidly transformed into kinetic energy as the coaster descends; the chemical energy of gasoline is transformed into the kinetic energy of your moving car. The following table illustrates a few common energy transformations. In this table, we use an arrow → as a shorthand way of representing an energy transformation.

Some energy transformations

A weightlifter lifts a barbell over her head

The barbell has much more gravitational potential energy when high above her head than when on the floor. To lift the barbell, she is transforming chemical energy in her body into gravitational potential energy of the barbell.

$$E_{\text{chem}} \rightarrow U_g$$



A base runner slides into the base

When running, he has lots of kinetic energy. After sliding, he has none. His kinetic energy is transformed mainly into thermal energy: The ground and his legs are slightly warmer.

$$K \rightarrow E_{\text{th}}$$

A burning campfire

The wood contains considerable chemical energy. When the carbon in the wood combines chemically with oxygen in the air, this chemical energy is transformed largely into thermal energy of the hot gases and embers.

$$E_{\text{chem}} \rightarrow E_{\text{th}}$$

A springboard diver

Here's a two-step energy transformation. At the instant shown, the board is flexed to its maximum extent, so that elastic potential energy stored in the board. Soon this energy will begin to be transformed into kinetic energy; as the diver rises into the air and slows, this kinetic energy will be transformed into gravitational potential energy.

$$U_s \rightarrow K \rightarrow U_g$$

As we saw in Chapter 10, energy can't be created or destroyed; it can only be converted from one form to another. When we say we are *using energy,* we mean that we are transforming it, such as transforming the chemical energy of food into the kinetic energy of your body. Let's revisit the idea of energy transformations, considering some realistic situations that have interesting theoretical and practical limitations.

Energy transformations

Light energy hitting a solar cell on top of these walkway lights is converted to electric energy and then stored as chemical energy in a battery.

At night, the battery's chemical energy is converted to electric energy that is then converted to light energy in a light-emitting diode.

Light energy is absorbed by photosynthetic pigments in soybean plants, which use this energy to create concentrated chemical energy.

The soybeans are harvested and their oil is used to make candles. When the candle burns, the stored chemical energy is transformed into light energy and thermal energy.

A wind turbine converts the translational kinetic energy of moving air into electric energy.

Miles away, this energy can be used by a fan, which transforms the electric energy back into the kinetic energy of moving air.

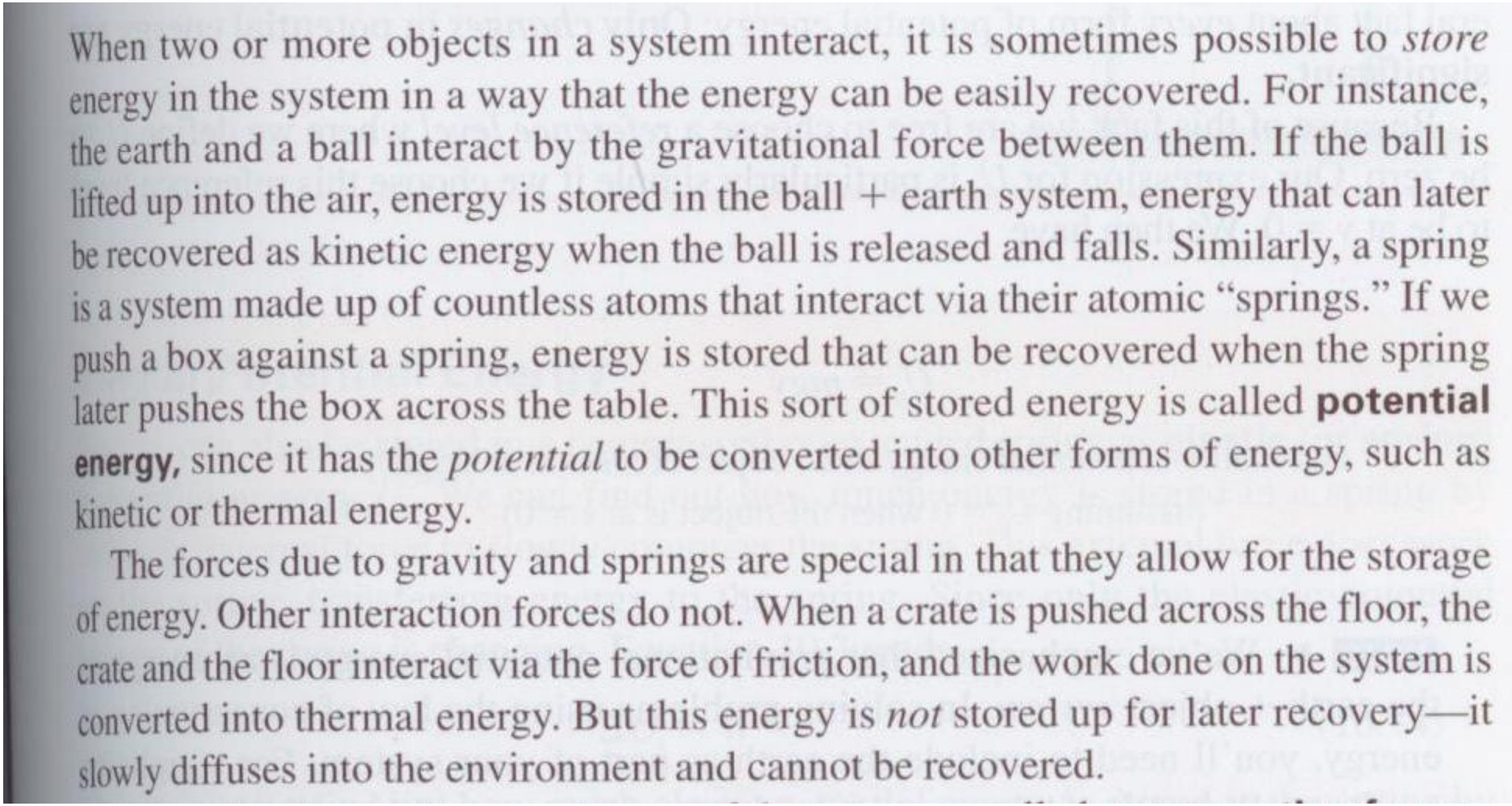
FIGURE 10.12 The large rotating blades of a windmill have a great deal of kinetic energy.

FIGURE 10.13 Rotational kinetic energy is due to the circular motion of the particles.

Rotational Kinetic Energy

◀ Rotational recharge The International Space Station (ISS) gets its electric power from solar panels. But during each 92-minute orbit, the ISS is in the earth's shadow for 30 minutes. The batteries that currently provide power during these blackouts need periodic replacement, which is very expensive in space. A promising new technology would replace the batteries with a *flywheel*—a cylinder rotating at a very high angular speed. Energy from the solar panels is used to speed up the flywheel, storing energy as rotational kinetic energy, which can then be converted back into electric energy when the ISS is in shadow.

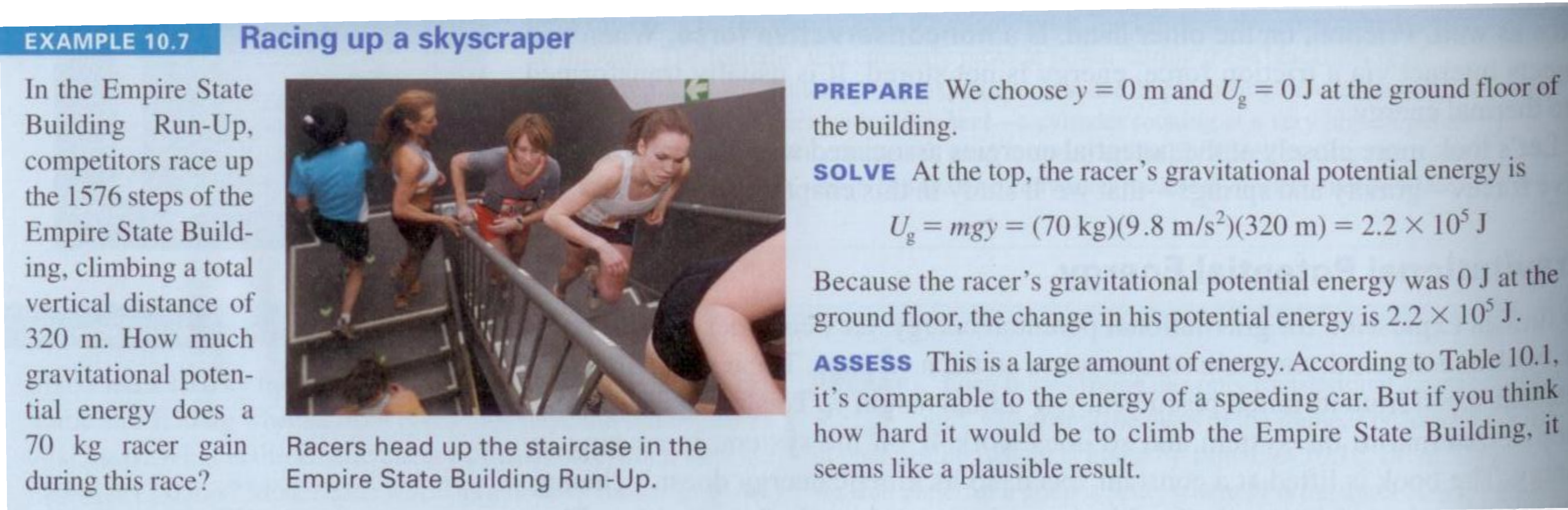
Potential Energy



When two or more objects in a system interact, it is sometimes possible to *store* energy in the system in a way that the energy can be easily recovered. For instance, the earth and a ball interact by the gravitational force between them. If the ball is lifted up into the air, energy is stored in the ball + earth system, energy that can later be recovered as kinetic energy when the ball is released and falls. Similarly, a spring is a system made up of countless atoms that interact via their atomic "springs." If we push a box against a spring, energy is stored that can be recovered when the spring later pushes the box across the table. This sort of stored energy is called **potential energy,** since it has the *potential* to be converted into other forms of energy, such as kinetic or thermal energy.

The forces due to gravity and springs are special in that they allow for the storage of energy. Other interaction forces do not. When a crate is pushed across the floor, the crate and the floor interact via the force of friction, and the work done on the system is converted into thermal energy. But this energy is *not* stored up for later recovery—it slowly diffuses into the environment and cannot be recovered.

Gravitational Potential Energy



EXAMPLE 10.7 **Racing up a skyscraper**

In the Empire State Building Run-Up, competitors race up the 1576 steps of the Empire State Building, climbing a total vertical distance of 320 m. How much gravitational potential energy does a 70 kg racer gain during this race?

Racers head up the staircase in the Empire State Building Run-Up.

PREPARE We choose $y = 0$ m and $U_g = 0$ J at the ground floor of the building.

SOLVE At the top, the racer's gravitational potential energy is

$$U_g = mgy = (70 \text{ kg})(9.8 \text{ m/s}^2)(320 \text{ m}) = 2.2 \times 10^5 \text{ J}$$

Because the racer's gravitational potential energy was 0 J at the ground floor, the change in his potential energy is 2.2×10^5 J.

ASSESS This is a large amount of energy. According to Table 10.1, it's comparable to the energy of a speeding car. But if you think how hard it would be to climb the Empire State Building, it seems like a plausible result.

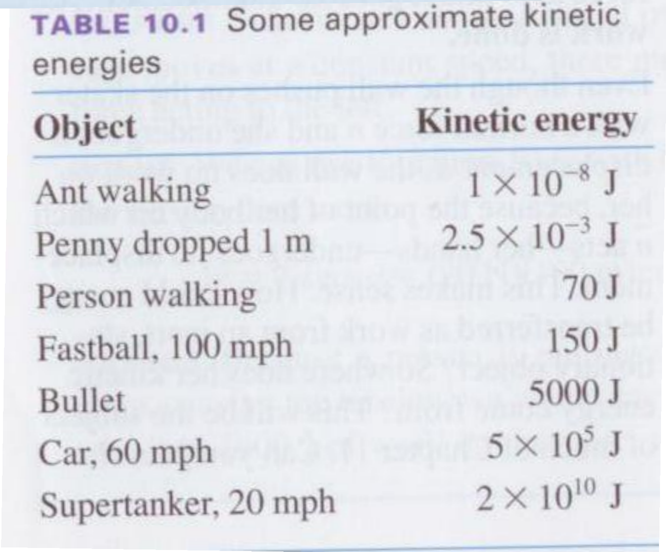
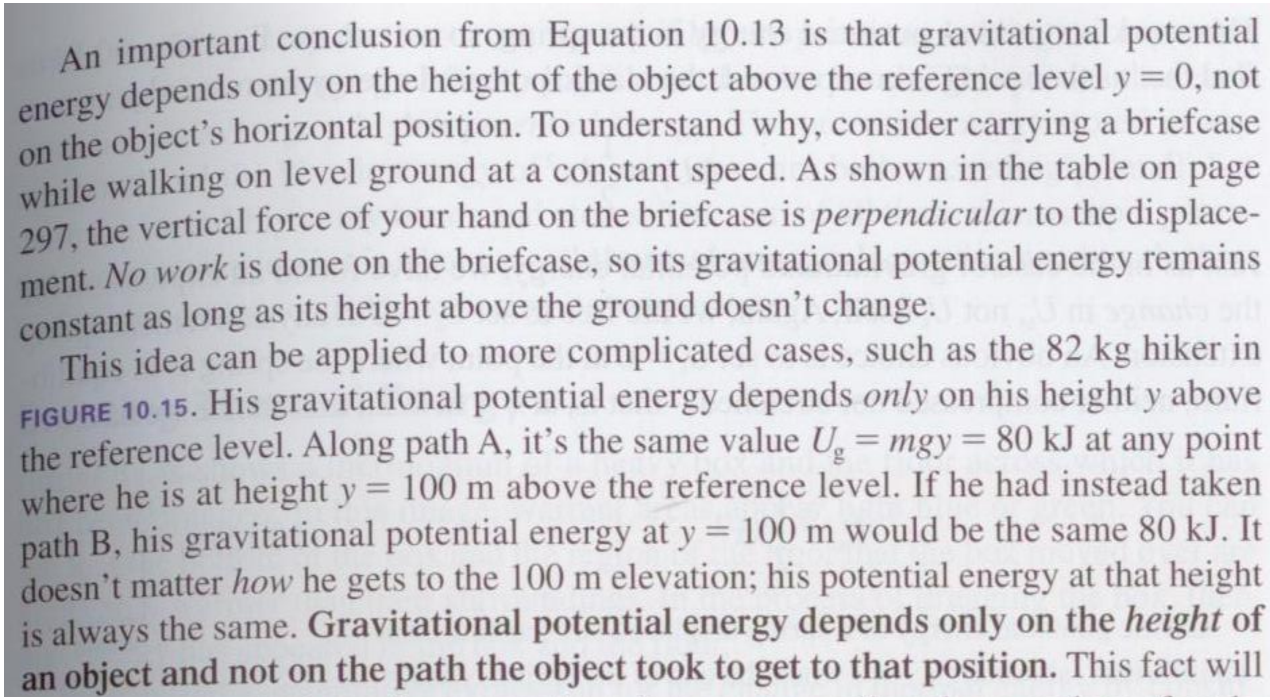


TABLE 10.1 Some approximate kinetic energies

Object	Kinetic energy
Ant walking	1×10^{-8} J
Penny dropped 1 m	2.5×10^{-3} J
Person walking	70 J
Fastball, 100 mph	150 J
Bullet	5000 J
Car, 60 mph	5×10^5 J
Supertanker, 20 mph	2×10^{10} J

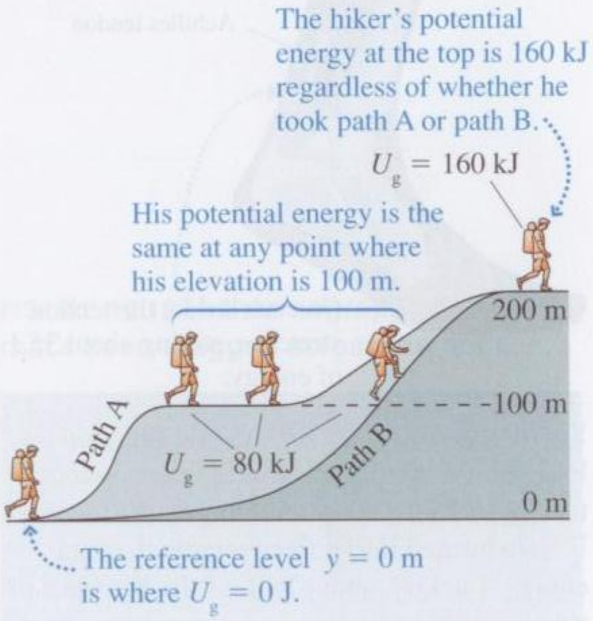
Gravitational Potential Energy = $U_g = mgy$



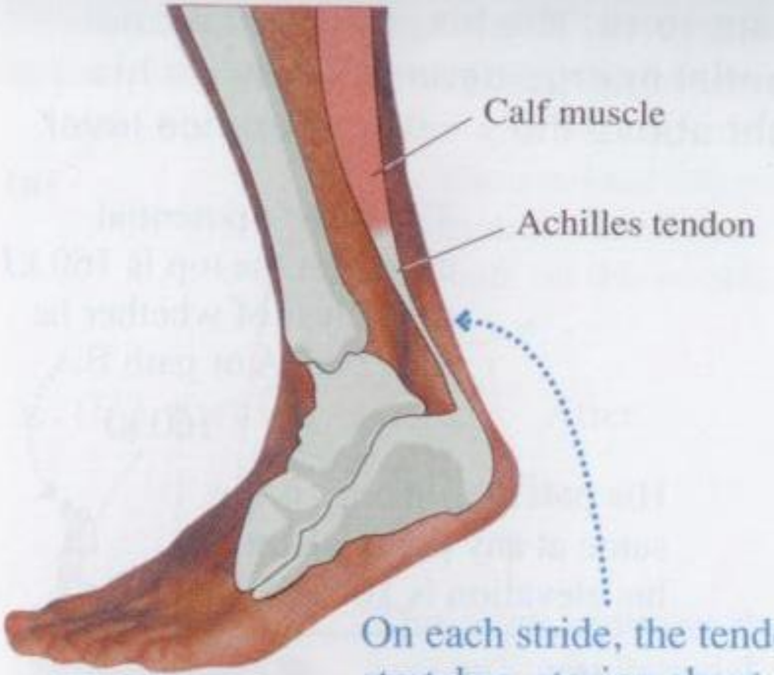
An important conclusion from Equation 10.13 is that gravitational potential energy depends only on the height of the object above the reference level $y = 0$, not on the object's horizontal position. To understand why, consider carrying a briefcase while walking on level ground at a constant speed. As shown in the table on page 297, the vertical force of your hand on the briefcase is *perpendicular* to the displacement. *No work* is done on the briefcase, so its gravitational potential energy remains constant as long as its height above the ground doesn't change.

This idea can be applied to more complicated cases, such as the 82 kg hiker in **FIGURE 10.15**. His gravitational potential energy depends *only* on his height y above the reference level. Along path A, it's the same value $U_g = mgy = 80$ kJ at any point where he is at height $y = 100$ m above the reference level. If he had instead taken path B, his gravitational potential energy at $y = 100$ m would be the same 80 kJ. It doesn't matter *how* he gets to the 100 m elevation; his potential energy at that height is always the same. **Gravitational potential energy depends only on the *height* of an object and not on the path the object took to get to that position.** This fact will

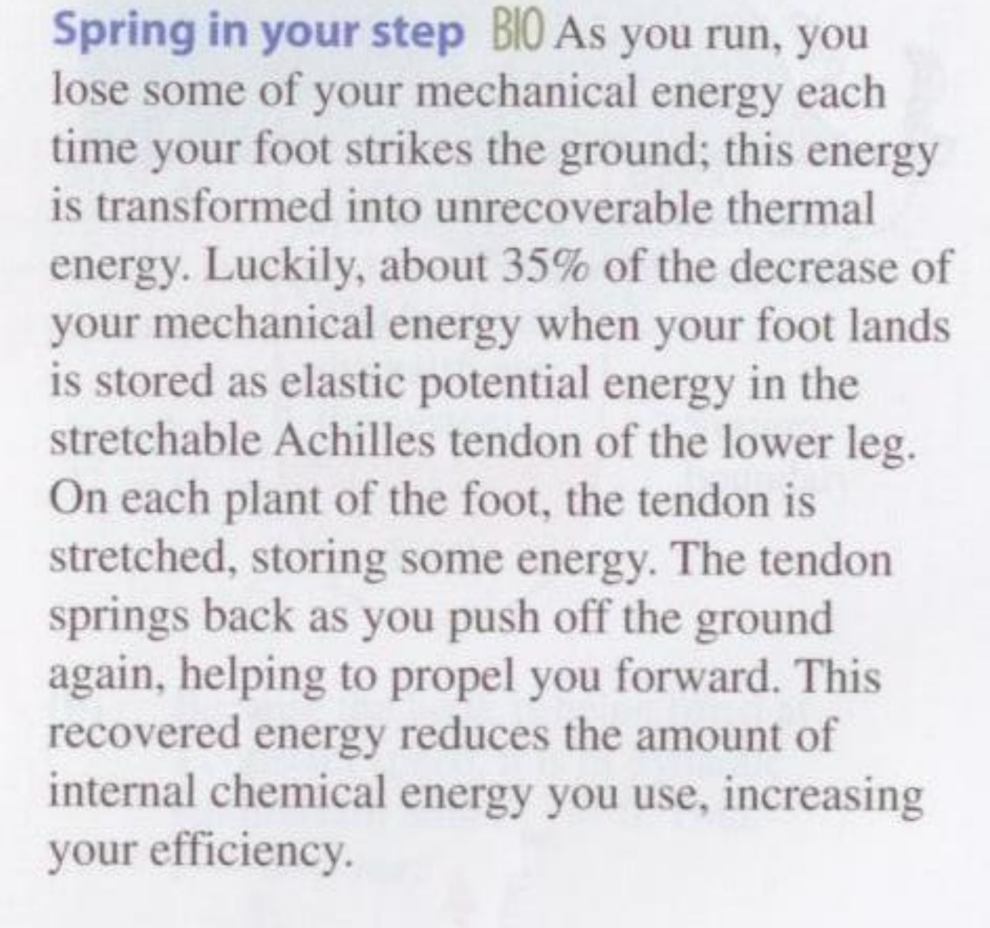
FIGURE 10.15 The hiker's gravitational potential energy depends only on his height above the $y = 0$ m reference level.



Elastic Potential Energy

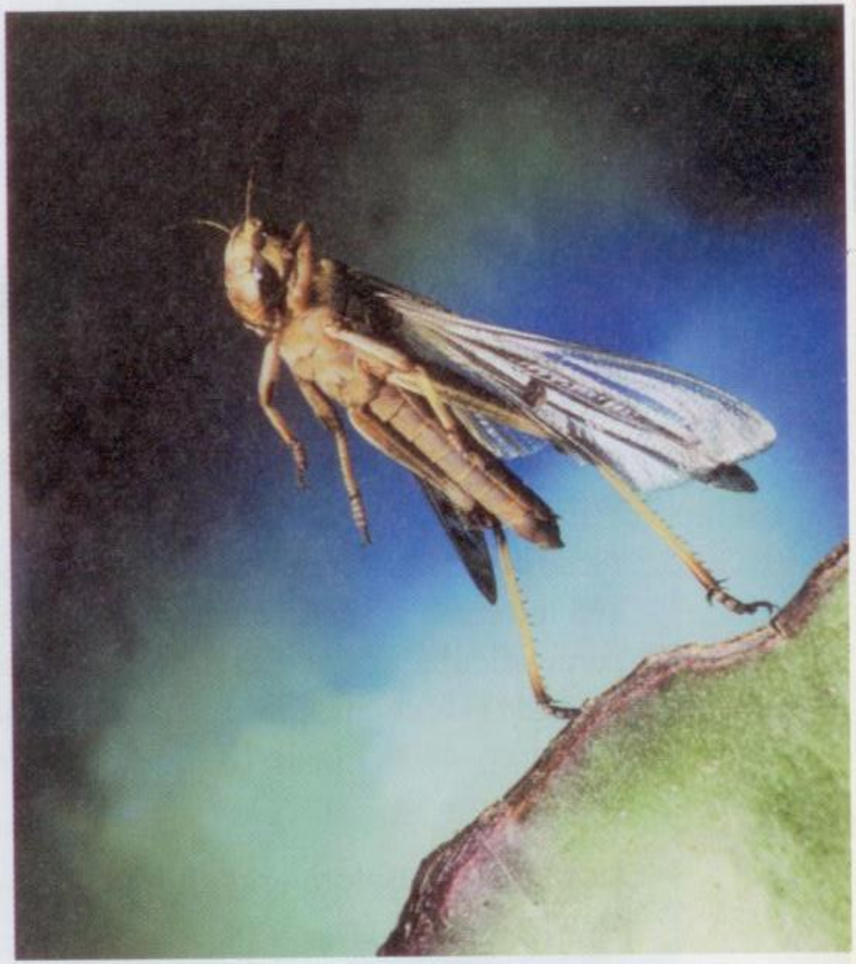


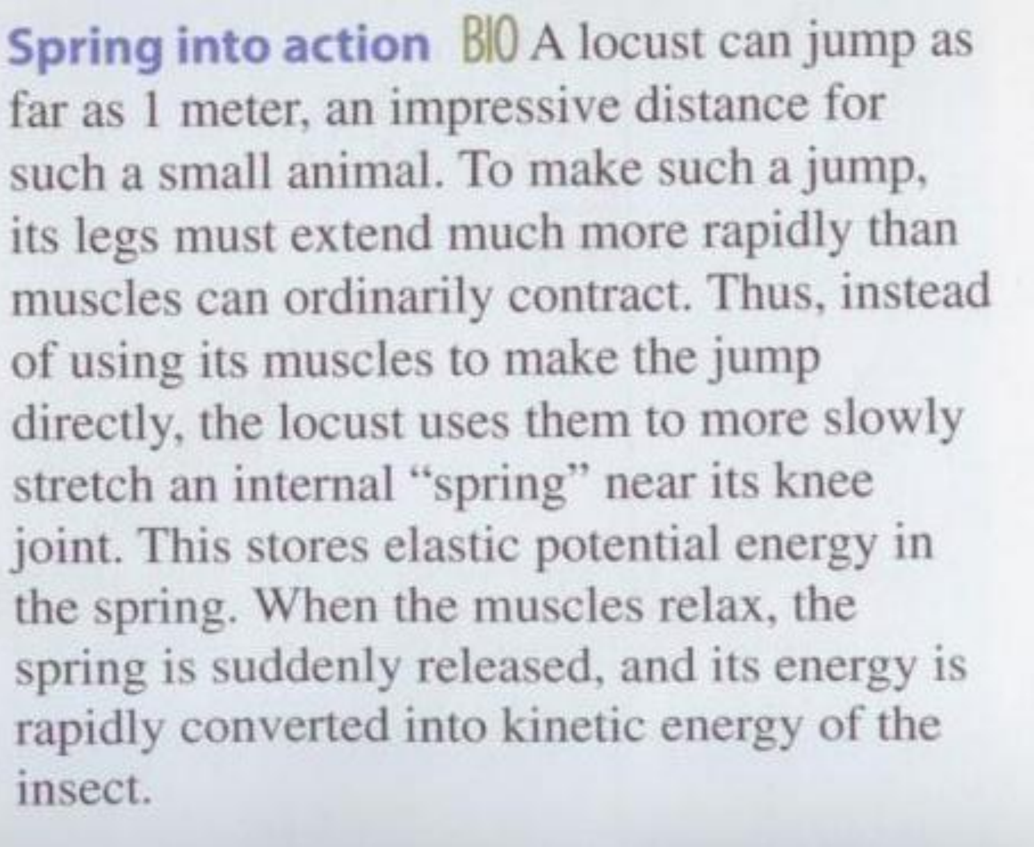
On each stride, the tendon stretches, storing about 35 J of energy.



Spring in your step BIO As you run, you lose some of your mechanical energy each time your foot strikes the ground; this energy is transformed into unrecoverable thermal energy. Luckily, about 35% of the decrease of your mechanical energy when your foot lands is stored as elastic potential energy in the stretchable Achilles tendon of the lower leg. On each plant of the foot, the tendon is stretched, storing some energy. The tendon springs back as you push off the ground again, helping to propel you forward. This recovered energy reduces the amount of internal chemical energy you use, increasing your efficiency.

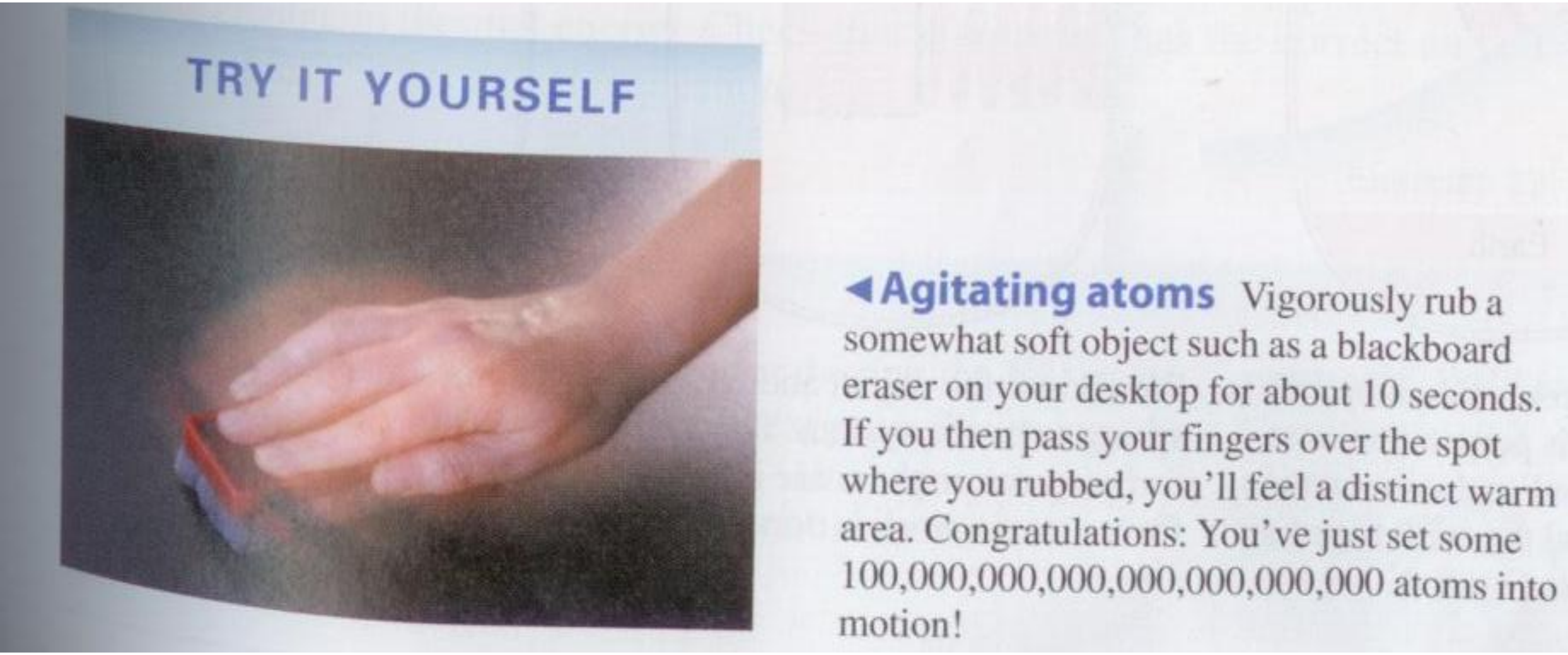
Elastic Potential Energy





Spring into action BIO A locust can jump as far as 1 meter, an impressive distance for such a small animal. To make such a jump, its legs must extend much more rapidly than muscles can ordinarily contract. Thus, instead of using its muscles to make the jump directly, the locust uses them to more slowly stretch an internal "spring" near its knee joint. This stores elastic potential energy in the spring. When the muscles relax, the spring is suddenly released, and its energy is rapidly converted into kinetic energy of the insect.

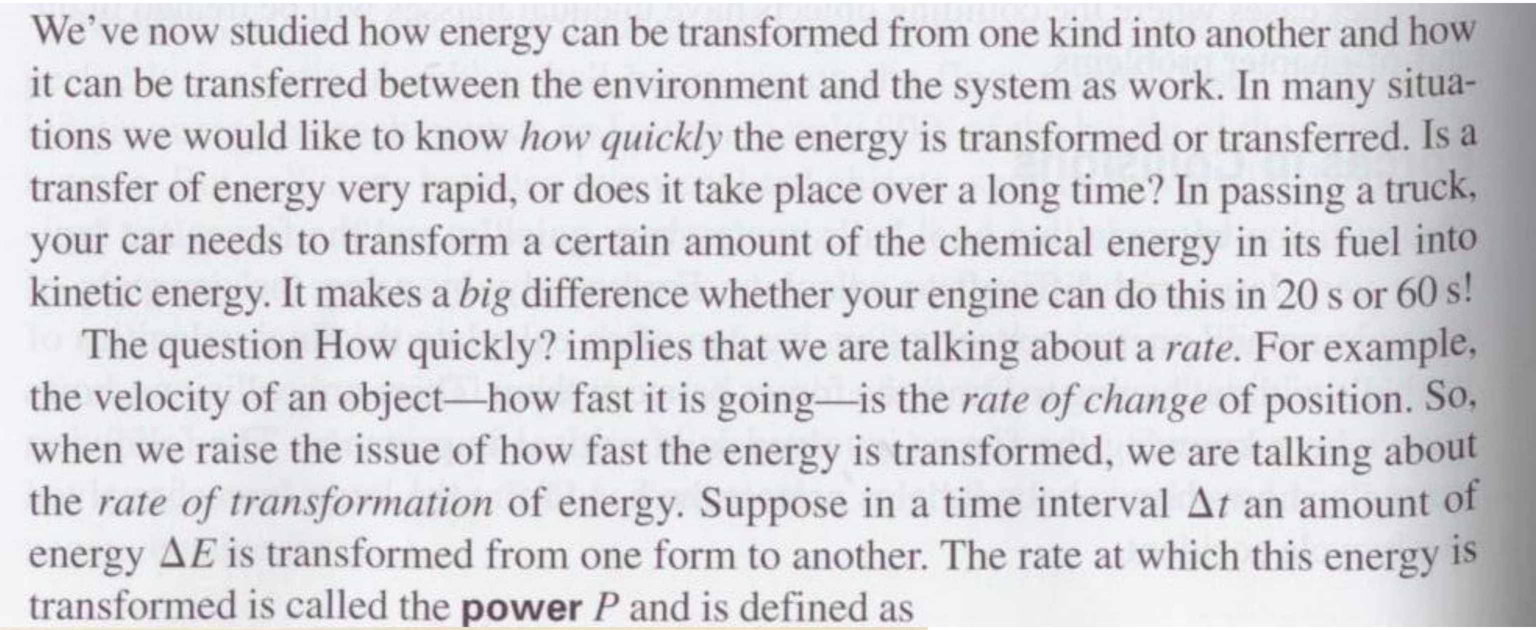
Thermal Energy



TRY IT YOURSELF

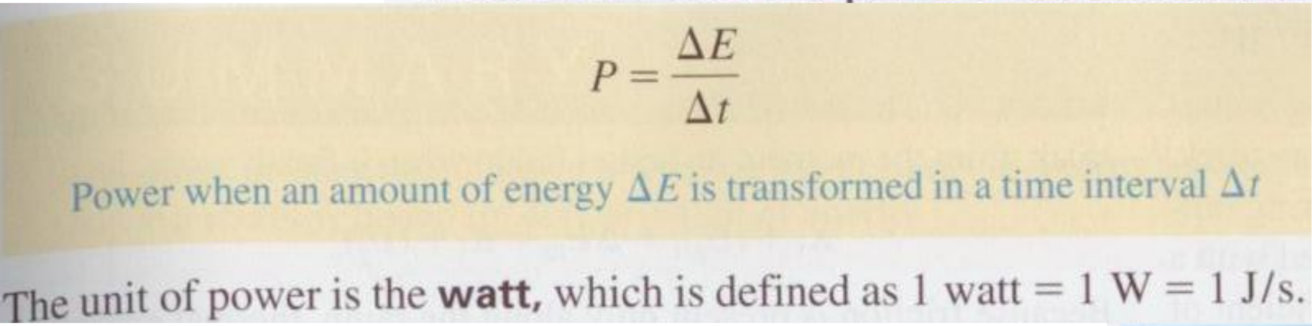
◄**Agitating atoms** Vigorously rub a somewhat soft object such as a blackboard eraser on your desktop for about 10 seconds. If you then pass your fingers over the spot where you rubbed, you'll feel a distinct warm area. Congratulations: You've just set some 100,000,000,000,000,000,000,000 atoms into motion!

Power



We've now studied how energy can be transformed from one kind into another and how it can be transferred between the environment and the system as work. In many situations we would like to know *how quickly* the energy is transformed or transferred. Is a transfer of energy very rapid, or does it take place over a long time? In passing a truck, your car needs to transform a certain amount of the chemical energy in its fuel into kinetic energy. It makes a *big* difference whether your engine can do this in 20 s or 60 s!

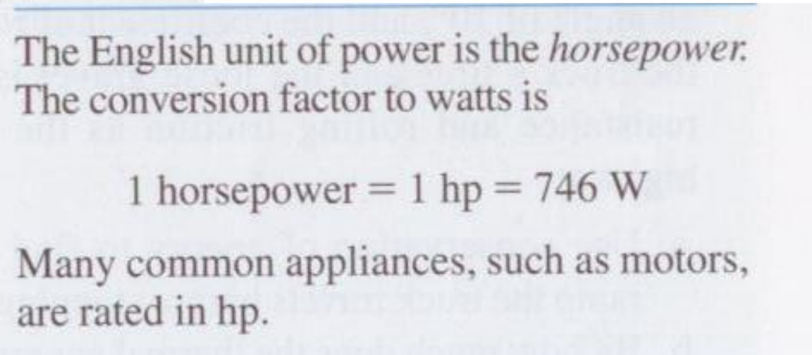
The question How quickly? implies that we are talking about a *rate*. For example, the velocity of an object—how fast it is going—is the *rate of change* of position. So, when we raise the issue of how fast the energy is transformed, we are talking about the *rate of transformation* of energy. Suppose in a time interval Δt an amount of energy ΔE is transformed from one form to another. The rate at which this energy is transformed is called the **power** P and is defined as



$$P = \frac{\Delta E}{\Delta t}$$

Power when an amount of energy ΔE is transformed in a time interval Δt

The unit of power is the **watt,** which is defined as 1 watt = 1 W = 1 J/s.

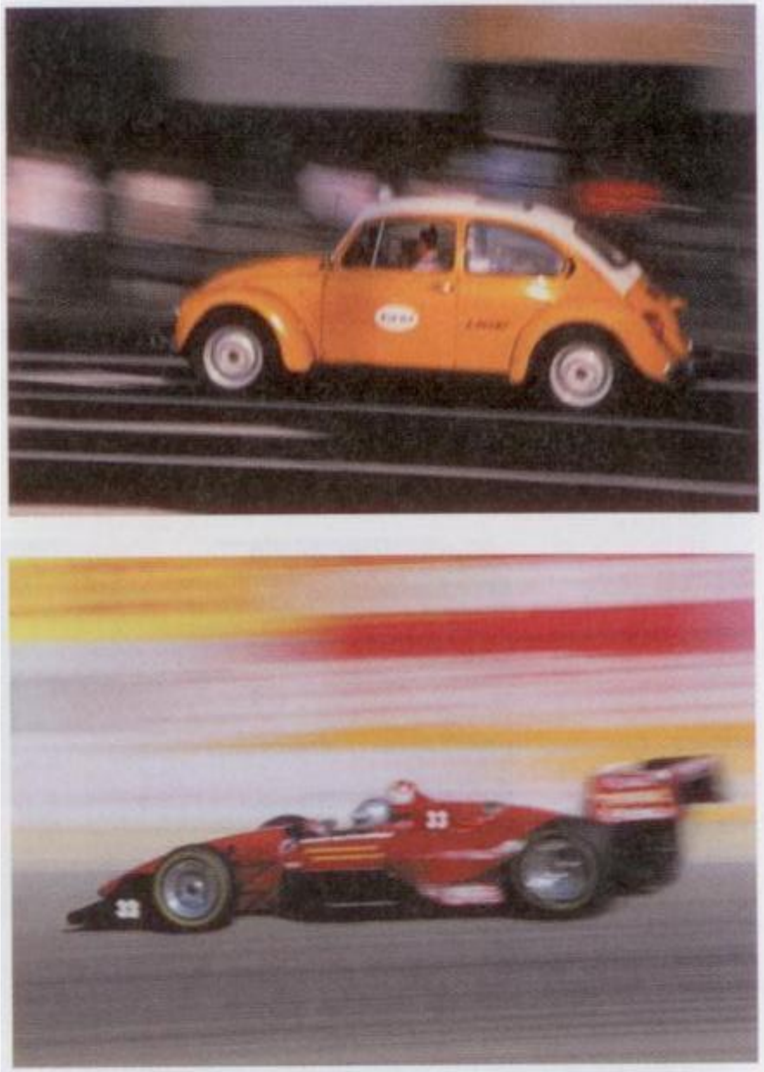


The English unit of power is the *horsepower.* The conversion factor to watts is

$$1 \text{ horsepower} = 1 \text{ hp} = 746 \text{ W}$$

Many common appliances, such as motors, are rated in hp.

Power



Both these cars take about the same energy to reach 60 mph, but the race car gets there in a much shorter time, so its *power* is much greater.