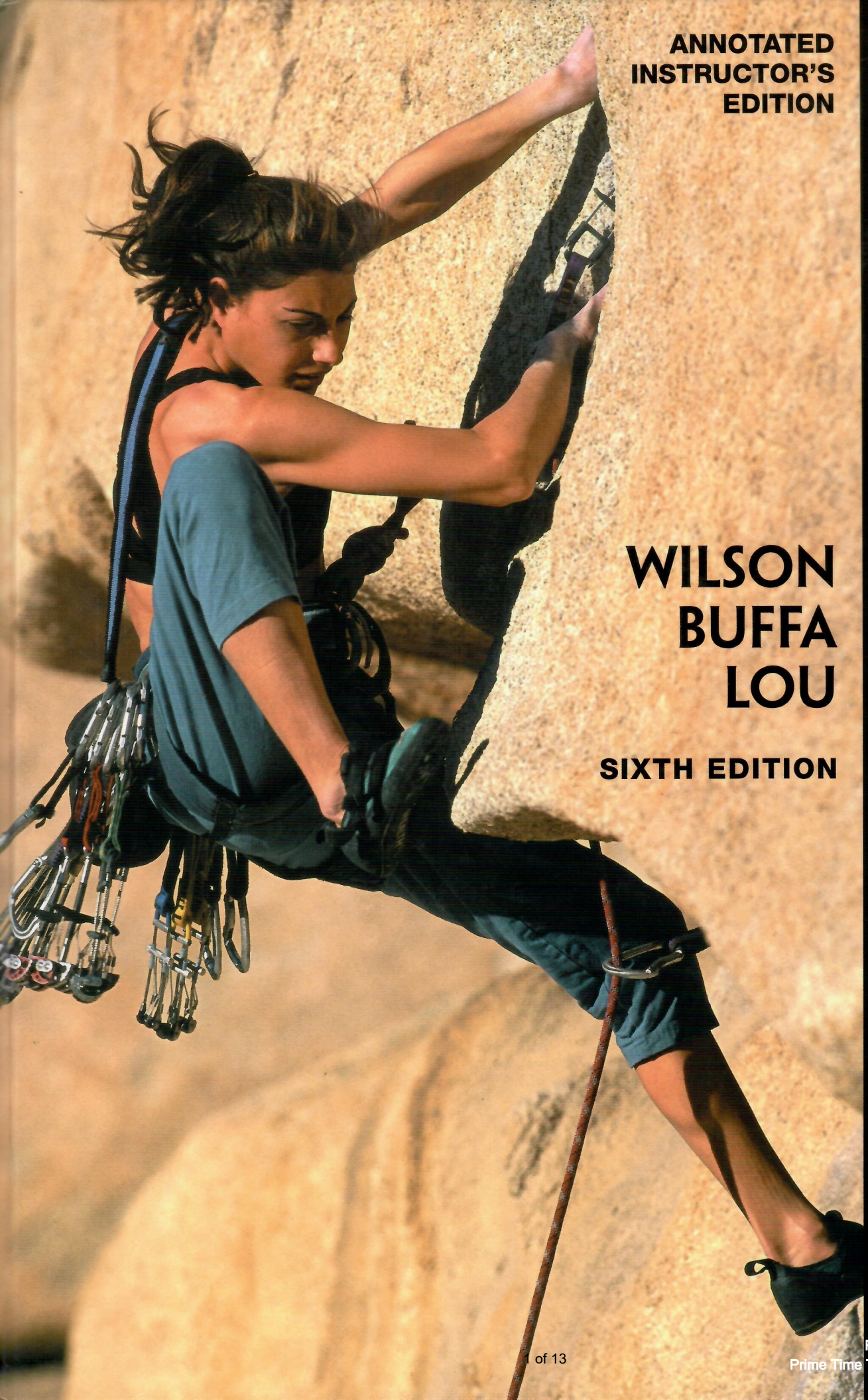

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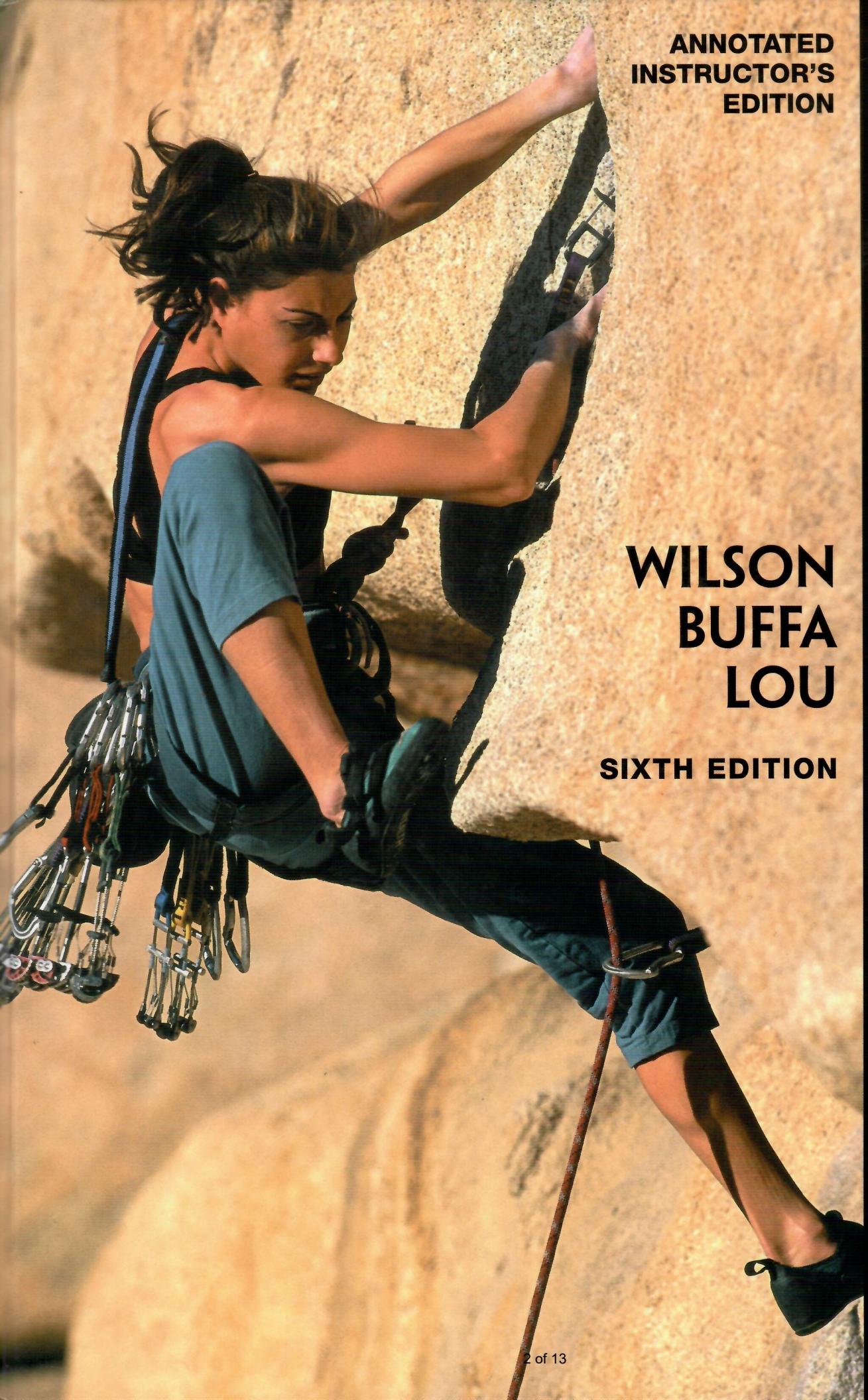

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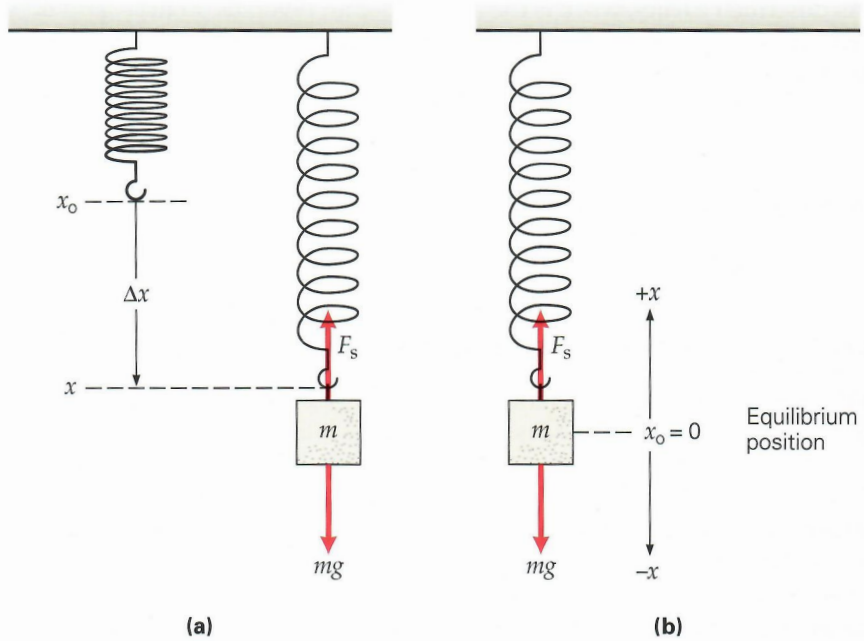

▶ **FIGURE 5.8 Displacement reference** The reference position x_o is arbitrary and is usually chosen for convenience. It may be **(a)** at the end of the spring at its unloaded position or **(b)** at the equilibrium position when a mass is suspended on the spring. The latter is particularly convenient in cases in which the mass oscillates up and down on the spring.

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Illustration 6.4 Springs

5.3 The Work–Energy Theorem: Kinetic Energy

OBJECTIVES: To (a) study the work–energy theorem, and (b) apply it in solving problems.

Now that we have an operational definition of work, let's take a look at how work is related to energy. Energy is one of the most important concepts in science. We describe it as a quantity that objects or systems possess. Basically, work is something that is *done on* objects, whereas energy is something that objects *have*—the ability to do work.

One form of energy that is closely associated with work is *kinetic energy*. (Another form of energy, *potential energy*, will be described in Section 5.4.) Consider an object at rest on a frictionless surface. Let a horizontal force act on the object and set it in motion. Work is done *on* the object, but where does the work "go," so to speak? It goes into setting the object into motion, or changing its *kinetic* conditions. Because of its motion, we say the object has gained energy—kinetic energy, which gives it the capability to do work.

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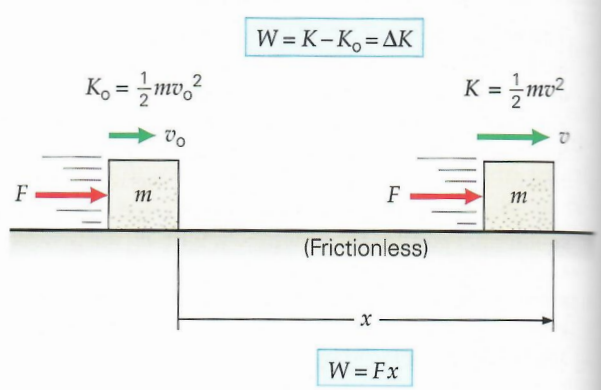
Exploration 6.1 An Operational Definition of Work

For a constant force doing work on a moving object, as illustrated in ▼Fig. 5.9, the force does an amount of work $W = Fx$. But what are the kinematic effects? The force gives the object a constant acceleration, and from Eq. 2.12, $v^2 = v_o^2 + 2ax$ (with $x_o = 0$),

$$a = \frac{v^2 - v_o^2}{2x}$$



▶ **FIGURE 5.9 The relationship of work and kinetic energy** The work done on a block by a constant force in moving it along a horizontal frictionless surface is equal to the change in the block's kinetic energy: $W = \Delta K$.

where α, may or may not be zero. Writing the magnitude of the force in the form of Newton's second law and substituting in the expression for a from the previous equation gives

$$F = ma = m\left(\frac{v^2 - v_o^2}{2x}\right)$$

Using this expression in the equation for work, we have

$$W = Fx = m\left(\frac{v^2 - v_o^2}{2x}\right)x$$
$$= \tfrac{1}{2}mv^2 - \tfrac{1}{2}mv_o^2$$

It is convenient to define $\frac{1}{2}mv^2$ as the **kinetic energy (K)** of the moving object:

$$K = \tfrac{1}{2}mv^2 \quad \textit{(kinetic energy)} \tag{5.5}$$

SI unit of energy: joule (J)

Kinetic energy is often called the *energy of motion*. Note that it is directly proportional to the square of the (instantaneous) speed of a moving object, and therefore cannot be negative.

Then, in terms of kinetic energy, the previous expression for work can be written as

$$W = \tfrac{1}{2}mv^2 - \tfrac{1}{2}mv_o^2 = K - K_o = \Delta K$$

or

$$W = \Delta K \tag{5.6}$$

where it is understood that W *is the net work if more than one force acts on the object*, as shown in Example 5.3. This equation is called the **work–energy theorem**, and it relates the work done on an object to the change in the object's kinetic energy. That is, *the net work done on a body by all the forces acting on it is equal to the change in kinetic energy of the body*. Both work and energy have units of joules, and both are scalar quantities. Keep in mind that the work–energy theorem is true in general for variable forces and not just for the special case considered in deriving Eq. 5.5.

To illustrate that net work is equal to the change in kinetic energy, recall that in Example 5.1 the force of gravity did +44 J of work on a book that fell from rest through a distance of $y = 3.0$ m. At that position and instant, the falling book had 44 J of kinetic energy. Since $v_o = 0$ in this case, $\frac{1}{2}mv^2 = mgy$. Substituting this expression into the equation for the work done on the falling book by gravity, we get

$$W = Fd = mgy = \frac{mv^2}{2} = K = \Delta K$$

where $K_o = 0$. Thus the kinetic energy gained by the book is equal to the net work done on it: 44 J in this case. (As an exercise, confirm this fact by calculating the speed of the book and evaluating its kinetic energy.)

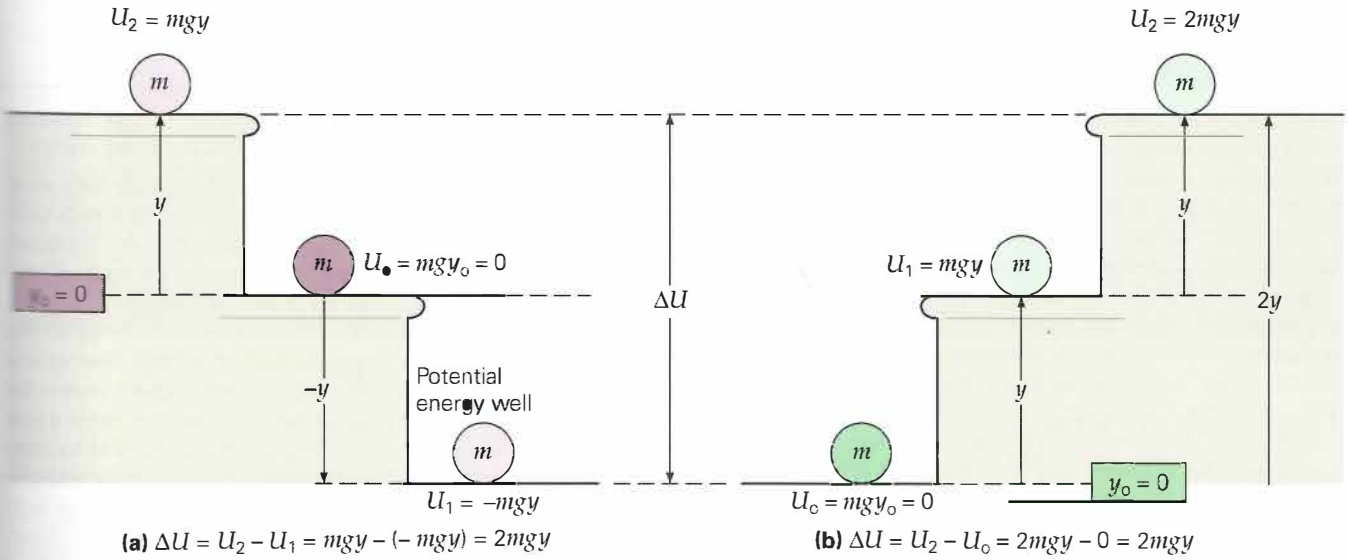
The work–energy theorem tells us that when work is done on an object, there is a change in or a transfer of energy. In general, then, we might say that work is a measure of *the transfer of kinetic energy* to the object. For example, a force doing work on an object that causes the object to speed up gives rise to an increase in the object's kinetic energy. Conversely, (negative) work done by the force of kinetic friction may cause a moving object to slow down and decrease its kinetic energy. So for an object to have a change in its kinetic energy, net work must be done on the object, as Eq. 5.6 tells us.

When an object is in motion, it possesses kinetic energy and has the capability to do work. For example, a moving automobile has kinetic energy and can do work in crumpling a fender in a fenderbender—not *useful* work in that case, but still work. Another example of work done by kinetic energy is shown in ▸Fig. 5.10.

Teaching tip: Emphasize that net work done causes a change in kinetic energy. Discuss the process of pitching and catching a baseball. Catching a baseball involves negative work, which decreases kinetic energy. Toss a ball to a student to initiate the discussion.

Work–energy theorem

▲ **FIGURE 5.10 Kinetic energy and work** A moving object, such as a wrecking ball, processes kinetic energy and can do work. A massive ball is used in demolishing buildings.



▲ **FIGURE 5.16 Reference point and change in potential energy** **(a)** The choice of a reference point (zero height) is arbitrary and may give rise to a negative potential energy. An object is said to be in a potential-energy well in this case. **(b)** The well may be avoided by selecting a new zero reference. Note that the difference, or *change*, in potential energy (ΔU) associated with the two positions is the same, regardless of the reference point. There is no physical difference, even though there are two coordinate systems and two different zero reference points.

Zero Reference Point

An important point is illustrated in Example 5.9, namely, the choice of a zero reference point. Potential energy is the energy of *position*, and the potential energy at a particular position (U) is meaningful only when referenced to the potential energy at some other position (U_0). The reference position or point is arbitrary, as is the origin of a set of coordinate axes for analyzing a system. Reference points are usually chosen with convenience in mind—for example, $y_0 = 0$. The value of the potential energy at a particular position depends on the reference point used. However, *the difference, or change, in potential energy associated with two positions is the same regardless of the reference position.*

If, in Example 5.9, ground level had been taken as the zero reference point, then U at the release point would not have been zero. However, U at the maximum height would have been greater, and $\Delta U = U - U_0$ would have been the same. This concept is illustrated in ▲Fig. 5.16. Note in Fig. 5.16a that the potential energy can be negative. When an object has a negative potential energy, it is said to be in a potential-energy *well*, which is analogous to being in an actual well: work is needed to raise the object to a higher position in the well or to get it out of the well.

It is also said that gravitational potential energy is *independent of path*. This means that only the change in height Δh (or Δy) is the consideration, not the path that leads to the change in height. An object could travel many paths leading to the same Δh.

Teaching tip: Make sure students understand that potential energy is a scalar quantity; however, unlike kinetic energy, it can be either positive or negative, depending on the choice of the zero position.

5.5 Conservation of Energy

OBJECTIVES: To (a) distinguish between conservative and nonconservative forces, and (b) explain their effects on the conservation of energy.

Conservation laws are the cornerstones of physics, both theoretically and practically. Most scientists would probably name conservation of energy as the most profound and far-reaching of these important laws. When we say that a physical quantity is *conserved*, we mean that it is constant, or has a constant value. Because so many things continually change in physical processes, conserved quantities are extremely helpful in our attempts to understand and describe the universe. Keep in mind, though, that many quantities are conserved only under special conditions.

One of the most important conservation laws is that concerning conservation of energy. (You may have seen this topic coming in Example 5.9.) A familiar statement is that the total energy of the universe is conserved. This statement is true, because

Demonstration/activity: Consider using this demonstration as an introduction to the conservation of energy. Suspend a 1-kg mass on a string 1–2 m long so the mass is about chest high. Pull the mass back through an angle of several degrees to a point right underneath your chin or just in front of your nose. Then release it from rest. The mass, conserving energy, will not hit you on return. (Don't give it a push, and don't move!)

INSIGHT 5.1 PEOPLE POWER: USING BODY ENERGY

The human body is energy inefficient. That is, a lot of energy doesn't go into doing useful work and is wasted. It would be advantageous to convert some of this energy into useful work. Attempts are being made to do this through "energy harvesting" from the human body. Normal body activities produce motion, flexing and stretching, compression, and body heat—this is energy there for the taking. Harvesting the energy is a difficult job, but using advances in nanotechnology (Chapter 1) and materials science, the effort is being made.

One older example of using body energy is the self-winding wristwatch, which is wound mechanically from the wearer's arm movements. (Today, batteries have all but taken over.) An ultimate goal in "energy harvesting" is to convert some of the body's energy into electricity—even if only a small amount. How might this be done? Here are a couple of ways:

- Piezoelectric devices. When mechanically stressed, piezoelectric substances, which like some ceramics, can generate electrical energy.
- Thermoelectric materials, which convert heat resulting from some temperature difference into electrical energy.

These methods have severe limitations and produce only small amounts of electricity. But with miniaturization and nanotechnology, the results could be enough. Researchers have already developed boots that use the compression of walking on a compound to produce enough energy to power a radio.

A more recent application is the "backpack generator." The mounted backpack's load is suspended by springs. The up and down hip motion of a person wearing the backpack makes the suspended load bounce up and down. This motion turns a gear connected to a simple magnetic coil generator, similar to those used in flashlights that are energized by a rhythmic shaking (see Insight 20.1, page 664). The body's mechanical energy with this device can generate up to 7 watts of electrical energy. A typical cell phone operates on about 1 watt. (The watt is a unit of power, J/s, energy/second, see Section 5.6).

Who knows what the future of technology may hold? Reflect on how many advances have occurred in your own lifetime.

Note: A system is a physical arrangement with real or imaginary boundaries. A classroom might be considered a system, and so might an arbitrary cubic meter of air.

the whole universe is taken to be a system. A *system* is defined as a definite quantity of matter enclosed by boundaries, either real or imaginary. In effect, the universe is the largest possible closed, or isolated, system we can imagine. Within a *closed system*, particles can interact with each other, but have absolutely no interaction with anything outside. In general, then, the amount of energy in a system remains constant when no mechanical work is done on or by the system, and no energy is transferred to or from the system (including thermal energy and radiation).

Thus, the **law of conservation of total energy** may be stated as follows:

Conservation of total energy

> The total energy of an isolated system is always conserved.

Within such a system, energy may be converted from one form to another, but the total amount of all forms of energy is constant, or unchanged. Total energy can never be created or destroyed. The use of body energy is discussed in the accompanying Insight 5.1.

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Illustration 7.1 Choice of System

Conceptual Example 5.10 ■ Violation of the Conservation of Energy?

A static, uniform liquid is in one side of a double container as shown in ▸Fig. 5.17a. If the valve is open, the level will fall, because the liquid has (gravitational) potential energy. This may be computed by assuming all the mass of the liquid to be concentrated at its center of mass, which is at a height $h/2$. (More on the center of mass in Chapter 6.) When the valve is open, the liquid flows into the container on the right, and when static equilibrium is reached, each container has liquid to a height of $h/2$, with centers of mass at $h/4$. This being the case, the potential energy of the liquid before opening the valve was $U_o = (mg)h/2$, and afterward, with half the total mass in each container (Fig. 5.16b), $U = (m/2)g(h/4) + (m/2)g(h/4) = 2(m/2)g(h/4) = (mg)h/4$. Whoa. Was half of the energy lost?

Reasoning and Answer. No; by the conservation of total energy, it must be around somewhere. Where might it have gone? When the liquid flows from one container to the other, because of internal friction and friction against the walls, half of the potential energy is converted to heat (thermal energy), which is transferred to the surroundings as the liquid comes to equilibrium. (This means the same temperature and no internal fluctuations.)

Follow-Up Exercise. What would happen in this Example in the absence of friction?

6.1 Linear Momentum

OBJECTIVE: To define and compute linear momentum and the components of momentum.

The term *momentum* may bring to mind a football player running down the field, knocking down players who are trying to stop him. Or you might have heard someone say that a team lost its momentum (and so lost the game). Such everyday usages give some insight into the meaning of momentum. They suggest the idea of mass in motion and therefore of inertia. We tend to think of heavy or massive objects in motion as having a great deal of momentum, even if they move very slowly. However, according to the technical definition of momentum, a light object can have just as much momentum as a heavier one, and sometimes more.

Newton referred to what modern physicists term **linear momentum (p)** as "the quantity of motion . . . arising from velocity and the quantity of matter conjointly." In other words, the momentum of a body is proportional to *both* its mass and its velocity. By definition,

Note: The momentum vector of a single object is in the direction of the object's velocity.

the linear momentum of an object is the product of its mass and velocity:

$$\vec{\mathbf{p}} = m\vec{\mathbf{v}} \tag{6.1}$$

SI unit of momentum: kilogram-meter per second (kg · m/s)

Teaching tip: Stress that linear momentum is a vector quantity.

It is common to refer to linear momentum as simply *momentum*. Momentum is a vector quantity that has the same direction as the velocity, and x–y components with magnitudes of $p_x = mv_x$ and $p_y = mv_y$, respectively.

Equation 6.1 expresses the momentum of a single object or particle. For a system of more than one particle, the **total linear momentum** ($\vec{\mathbf{P}}$) of the system is the vector sum of the *momenta* (plural of *momentum*) of the individual particles:

Note: Total linear momentum—a vector sum

$$\vec{\mathbf{P}} = \vec{\mathbf{p}}_1 + \vec{\mathbf{p}}_2 + \vec{\mathbf{p}}_3 + \cdots = \sum \vec{\mathbf{p}}_i \tag{6.2}$$

(*Note*: $\vec{\mathbf{P}}$ signifies the *total* momentum, while $\vec{\mathbf{p}}$ signifies an *individual* momentum.)

Example 6.1 ■ Momentum: Mass and Velocity

A 100-kg football player runs with a velocity of 4.0 m/s straight down the field. A 1.0-kg artillery shell leaves the barrel of a gun with a muzzle velocity of 500 m/s. Which has the greater momentum (magnitude), the football player or the shell?

Thinking It Through. Given the mass and velocity of an object, the magnitude of its momentum can be calculated from Eq. 6.1.

Solution. As usual, we first list the given data and what is to be found, using the subscripts p and s to refer to the player and shell, respectively.

Given: $m_p = 100$ kg, $v_p = 4.0$ m/s, $m_s = 1.0$ kg, $v_s = 500$ m/s

Find: p_p and p_s (magnitudes of the momenta)

The magnitude of the momentum of the football player is

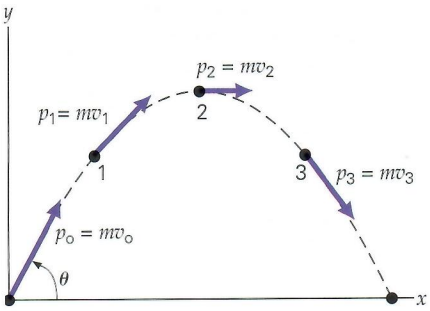
$$p_p = m_p v_p = (100\text{ kg})(4.0\text{ m/s}) = 4.0 \times 10^2\text{ kg}\cdot\text{m/s}$$

and that of the shell is

$$p_s = m_s v_s = (1.0\text{ kg})(500\text{ m/s}) = 5.0 \times 10^2\text{ kg}\cdot\text{m/s}$$

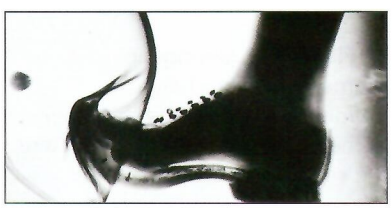
Thus, the less massive shell has the greater momentum. Remember, the magnitude of momentum depends on *both* the mass *and* the magnitude of the velocity.

Follow-Up Exercise. What would the football player's speed have to be for his momentum to have the same magnitude as the artillery shell's momentum? Would this speed be realistic? *(Answers to all Follow-Up Exercises are at the back of the text.)*

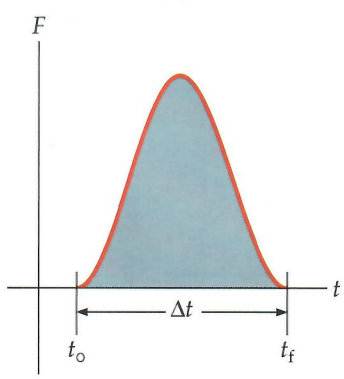


▲ **FIGURE 6.4 Change in the momentum of a projectile** The total momentum vector of a projectile is tangential to the projectile's path (as is its velocity); this vector changes in magnitude and direction, because of the action of an external force (gravity). The x-component of the momentum is constant. (Why?)

Demonstration/activity: Drop a good rubber ball (Super Ball) and an equivalent clay mass sequentially from equal heights onto a steel plate (ring-stand base) held by a student. The student holding the plate can feel which one gives the larger "push." Which one? Why?



(a)



(b)

▲ **FIGURE 6.5 Collision impulse** **(a)** Collision impulse causes the football to be deformed. **(b)** The impulse is the area under the curve of an F-versus-t graph. Note that the impulse force on the ball is not constant, but rises to a maximum.

Force and Momentum

As you know from Chapter 4, if an object has a change in velocity (an acceleration), a net force must be acting on it. Similarly, since momentum is directly related to velocity, a change in momentum also requires a net force. In fact, Newton originally expressed his second law of motion in terms of momentum rather than acceleration. The force–momentum relationship may be seen by starting with $\vec{\mathbf{F}}_{net} = m\vec{\mathbf{a}}$ and using $\vec{\mathbf{a}} = (\vec{\mathbf{v}} - \vec{\mathbf{v}}_o)/\Delta t$, where the mass is assumed to be constant. Thus,

$$\vec{\mathbf{F}}_{net} = m\vec{\mathbf{a}} = \frac{m(\vec{\mathbf{v}} - \vec{\mathbf{v}}_o)}{\Delta t} = \frac{m\vec{\mathbf{v}} - m\vec{\mathbf{v}}_o}{\Delta t} = \frac{\vec{\mathbf{p}} - \vec{\mathbf{p}}_o}{\Delta t} = \frac{\Delta\vec{\mathbf{p}}}{\Delta t}$$

or

$$\vec{\mathbf{F}}_{net} = \frac{\Delta\vec{\mathbf{p}}}{\Delta t} \quad \textit{Newton's second law of motion in terms of momentum} \tag{6.3}$$

where $\vec{\mathbf{F}}_{net}$ is the *average* net force on the object if the acceleration is not constant (or the *instantaneous* net force if Δt goes to zero).

Expressed in this form, Newton's second law states that *the net external force acting on an object is equal to the time rate of change of the object's momentum.* It is easily seen from the development of Eq. 6.3 that the equations $\vec{\mathbf{F}}_{net} = m\vec{\mathbf{a}}$ and $\vec{\mathbf{F}}_{net} = \Delta\vec{\mathbf{p}}/\Delta t$ are equivalent if the mass is constant. In some situations, however, the mass may vary. This factor will not be a consideration here in our discussion of particle collisions, but a special case will be given later in the chapter. The more general form of Newton's second law, Eq. 6.3, is true even if the mass varies.

Just as the equation $\vec{\mathbf{F}}_{net} = m\vec{\mathbf{a}}$ indicates that an acceleration is evidence of a net force, the equation $\vec{\mathbf{F}}_{net} = \Delta\vec{\mathbf{p}}/\Delta t$ indicates that *a change in momentum is evidence of a net force.* For example, as illustrated in ◂Fig. 6.4, the momentum of a projectile is tangential to the projectile's parabolic path and changes in both magnitude and direction. The change in momentum indicates that there is a net force acting on the projectile, which you know is the force of gravity. Changes in momentum were illustrated in Fig. 6.3. Can you identify the forces in these two cases? Think in terms of Newton's third law.

6.2 Impulse

OBJECTIVES: To relate (a) impulse and momentum, and (b) kinetic energy and momentum.

When two objects—such as a hammer and a nail, a golf club and a golf ball, or even two cars—collide, they can exert large forces on one another for a short period of time (◂Fig. 6.5a). The force is not constant in this situation. However, Newton's second law in momentum form is still useful for analyzing such situations by using average values. Written in this form, the law states that the *average* force is equal to the time rate of change of momentum: $\vec{\mathbf{F}}_{avg} = \Delta\vec{\mathbf{p}}/\Delta t$ (Eq. 6.3). Rewriting the equation to express the change in momentum, we have (with only one force acting on the object)

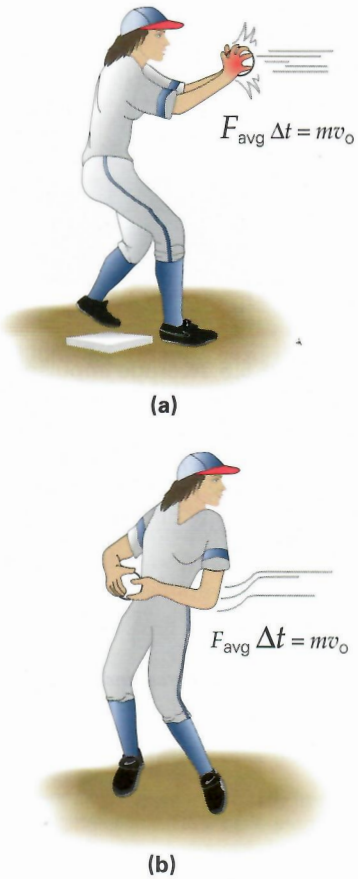
$$\vec{\mathbf{F}}_{avg}\Delta t = \Delta\vec{\mathbf{p}} = \vec{\mathbf{p}} - \vec{\mathbf{p}}_o \tag{6.4}$$

The term $\vec{\mathbf{F}}_{avg}\Delta t$ is known as the **impulse** ($\vec{\mathbf{I}}$) of the force:

$$\vec{\mathbf{I}} = \vec{\mathbf{F}}_{avg}\Delta t = \Delta\vec{\mathbf{p}} = m\vec{\mathbf{v}} - m\vec{\mathbf{v}}_o \tag{6.5}$$

SI unit of impulse and momentum: newton-second (N · s)

Thus, *the impulse exerted on an object is equal to the change in the object's momentum.* This statement is referred to as the **impulse–momentum theorem**. Impulse



▲ **FIGURE 6.7 Adjust the impulse** **(a)** The change in momentum in catching the ball is a constant mv_o. If the ball is stopped quickly (small Δt), the impulse force is large (big F_{avg}) and stings the catcher's bare hands. **(b)** Increasing the contact time (large Δt) by moving the hands with the ball reduces the impulse force and makes catching more enjoyable.

Example 6.4 illustrates the large forces that colliding objects can exert on one another during short contact times. In some cases, we shorten the contact time to maximize the impulse force—for example, in a karate chop. However, in other instances, the Δt may be manipulated to reduce the force. Suppose there is a fixed change in momentum in a given situation. Then, since $\Delta p = F_{avg}\Delta t$, if Δt could be made longer, the average impulse force F_{avg} would be reduced.

You have probably tried to minimize the impulse force on occasion. For example, in catching a hard, fast-moving ball, you quickly learn not to catch it with your arms rigid, but rather to move your hands with the ball. This movement increases the contact time and reduces the impulse force and the "sting" (◂Fig. 6.7).

When jumping from a height onto a hard surface, you try not to land stiff-legged. The abrupt stop (small Δt) would apply a large impulse force to your leg bones and joints and could cause injury. If you bend your knees as you land, the impulse is vertically upward, opposite your velocity ($F_{avg}\Delta t = \Delta p = -mv_o$, with the final velocity being zero). Thus, increasing the time interval Δt makes the impulse force smaller. Another example in which the contact time is increased to decrease the impulse force is given in Insight 6.1, The Automobile Air Bags and Martian Air Bags, on page 186.

Example 6.5 ■ Impulse Force and Body Injury

A 70.0-kg worker jumps stiff-legged from a height of 1.00 m onto a concrete floor. What is the magnitude of the impulse he feels on landing, assuming a sudden stop in 8.00 ms?

Thinking It Through. The impulse is $F_{avg}\Delta t$, which cannot be calculated directly from the given data. But impulse is equal to the change in momentum, $F_{avg}\Delta t = \Delta p = mv - mv_o$. So the impulse can be calculated from the difference in momenta.

Solution.

Given: $m = 70.0$ kg, $h = 1.00$ m, $\Delta t = 8.00$ ms $= 8.00 \times 10^{-3}$ s

Find: Impulse (I) on the worker

There are two different parts here: (a) the worker descending after jumping and (b) the sudden stop after hitting the floor. So we must be careful with notation.

(a) Here, $v_{o_1} = 0$, and the final velocity may be found using $v^2 = v_o^2 - 2gh$ (Eq. 2.12'), with the result of

$$v_1 = -\sqrt{2gh}$$

(b) The v_1 of the first process is then the initial velocity with which the stiff-legged worker hits the floor, that is, $v_{o_2} = v_1 = -\sqrt{2gh}$, and the final velocity at the second phase is $v_2 = 0$. Then,

$$I = F_{avg}\Delta t = \Delta p = mv_2 - mv_{o_2} = 0 - m(-\sqrt{2gh}) = +m\sqrt{2gh}$$
$$= (70.0\text{ kg})\sqrt{2(9.80\text{ m/s}^2)(1.00\text{ m})} = 310\text{ kg}\cdot\text{m/s}$$

where the impulse is in the upward direction.

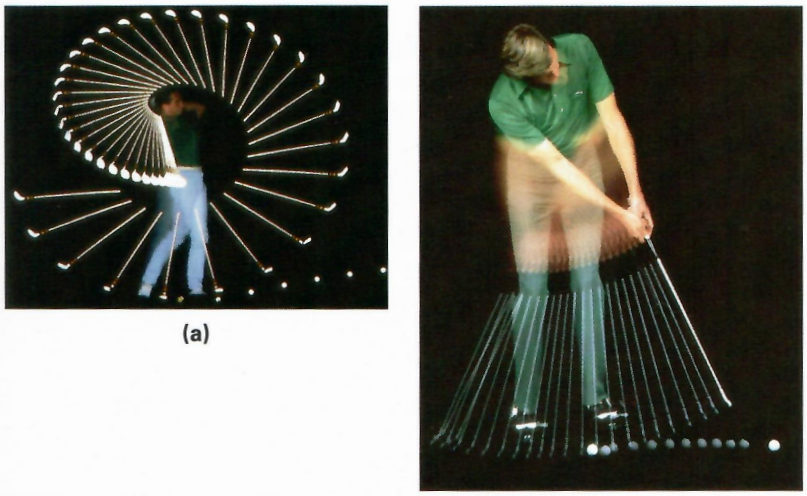
With a Δt of 6.0×10^{-3} s for the sudden stop on impact, this would give force of

$$F_{avg} = \frac{\Delta p}{\Delta t} = \frac{310\text{ kg}\cdot\text{m/s}}{8.00 \times 10^{-3}\text{ s}} = 3.88 \times 10^4\text{ N} \quad (\textit{about } 8.73 \times 10^3\text{ lb } \textit{of force!})$$

and the force is upward on the stiff legs.

Follow-Up Exercise. Suppose the worker bent his knees and increased the contact time to 0.60 s on landing. What would be the impulse force on him in this case?

In some instances, the applied impulse force may be relatively constant and the contact time (Δt) deliberately increased to produce a greater impulse, and thus a greater change in momentum ($F_{avg}\Delta t = \Delta p$). This is the principle of "following through" in sports, for example, when hitting a ball with a bat or racquet, or driving



(a) (b)

◀ **FIGURE 6.8 Increasing the contact time** **(a)** A golfer follows through on a drive. One reason he does so is to increase the contact time so that the ball receives greater impulse and momentum. **(b)** The follow-through on a long putt increases the contact time for greater momentum, but the main reason here is for directional control.

a golf ball. In the latter case (▲Fig. 6.8a), assuming that the golfer supplies the same average force with each swing, the longer the contact time, the greater will be the impulse or change in momentum the ball receives. That is, with $F_{avg}\Delta t = mv$ (since $v_0 = 0$), the greater the value of Δt, the greater will be the final speed of the ball. (This principle was illustrated in the Follow-Up Exercise in Example 6.4.) In some instances, a long follow-through that may primarily be used to improve control of the ball's direction (Fig. 6.8b).

The word *impulse* implies that the impulse force acts only briefly (like an "impulsive" person), and this is true in many instances. However, the definition of *impulse* places no limit on the time interval over which the force may act. Technically, a comet at its closest approach to the Sun is involved in a collision, because in physics, collision forces do *not* have to be contact forces. Basically, a **collision** is any interaction between objects in which there is an exchange of momentum and/or energy.

PHYSLET

Illustration 8.2 The Difference between Impulse and Work

As you might expect from the work–energy theorem and the impulse–momentum theorem, momentum and kinetic energy are directly related. A little algebraic manipulation of the equation for kinetic energy (Eq. 5.5) allows us to express kinetic energy (K) in terms of the *magnitude* of momentum (p):

$$K = \tfrac{1}{2}mv^2 = \frac{(mv)^2}{2m} = \frac{p^2}{2m} \tag{6.6}$$

Thus, kinetic energy and momentum are intimately related, but they are different quantities.

6.3 Conservation of Linear Momentum

OBJECTIVES: To (a) explain the conditions for the conservation of linear momentum, and (b) apply them to physical situations.

Like total mechanical energy, the total momentum of a system is a conserved quantity under certain conditions. This fact allows us to analyze a wide range of situations and solve many problems readily. Conservation of momentum is one of the most important principles in physics. In particular, it is used to analyze collisions of objects ranging from subatomic particles to automobiles in traffic accidents.

For the linear momentum of a single object to be conserved (that is, to remain constant with time), one condition must hold that is apparent from the momentum form of Newton's second law (Eq. 6.3). If the net force acting on a particle is zero, that is,

$$\vec{\mathbf{F}}_{net} = \frac{\Delta\vec{\mathbf{p}}}{\Delta t} = 0$$