# Chapter 5: Work and Energy

## Planning Guide

### Objectives

**PACING • 45 min**

**Chapter Opener**
- Recognize the difference between the scientific and ordinary definitions of work.
- Define work by relating it to force and displacement.
- Identify where work is being performed in a variety of situations.
- Calculate the net work done when many forces are applied to an object.

**PACING • 90 min**

**Section 2 Energy**
- Identify several forms of energy.
- Calculate kinetic energy for an object.
- Apply the work-kinetic energy theorem to solve problems.
- Distinguish between kinetic and potential energy.
- Classify different types of potential energy.
- Calculate the potential energy associated with an object's position.

**PACING • 90 min**

**Section 3 Conservation of Energy**
- Identify situations in which conservation of mechanical energy is valid.
- Recognize the forms that conserved energy can take.
- Solve problems using conservation of mechanical energy.

**PACING • 45 min**

**Section 4 Power**
- Relate the concepts of energy, time, and power.
- Calculate power in two different ways.
- Explain the effect of machines on work and power.

### Labs, Demonstrations, and Activities

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### Technology Resources

- CD Interactive Tutor Module 6, Work-Kinetic Energy Theorem <sup>GENERAL</sup>
- OSP Interactive Tutor Module 6, Worksheet <sup>GENERAL</sup>
- EXT Integrating Biology Muscles and Work <sup>BASIC</sup>
- TR 19 Friction and the Non-conservation of Mechanical Energy
- TR 19A Classification of Energy
- TR 20A Energy of a Falling 75 g Egg

### Online and Technology Resources

Visit go.hrw.com to access online resources. Click Holt Online Learning for an online edition of this textbook, or enter the keyword HF6 Home for other resources. To access this chapter's extensions, enter the keyword HF6WRKXT.

This CD-ROM package includes:
- Lab Materials QuickList Software
- Holt Calendar Planner
- Customizable Lesson Plans
- Printable Worksheets
- ExamView® Test Generator
- Interactive Teacher Edition
- Holt PuzzlePro®
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This CD-ROM consists of interactive activities that give students a fun way to extend their knowledge of physics concepts.
Section 1 introduces work and shows calculations of the work done in a variety of situations.

Section 2 identifies and shows calculations using kinetic energy, the work–kinetic energy theorem, and different types of potential energy.

Section 3 explores the conditions necessary for conservation of mechanical energy and applies this principle to problem solving.

Section 4 introduces the relationships among work, time, power, force, and speed.

About the Illustration
This audiokinetic sculpture was created by George Rhoads, whose sculptures can be seen at the Boston Museum of Science, at the Port Authority Bus Terminal in New York City, and in various shopping centers. After completing the chapter, have students return to this photograph and apply the concepts of work and the conservation of energy to describe which balls probably have mostly potential energy and which have mostly kinetic energy.

Interactive Problem-Solving Tutor
See Module 5
“Work” provides additional practice calculating net work.

See Module 6
“Work–Kinetic Energy Theorem” promotes additional development of problem-solving skills involving work.
This whimsical piece of art is called an audiokinetic sculpture. Balls are raised to a high point on the curved blue track. As the balls move down the track, they turn levers, spin rotors, and bounce off elastic membranes. The energy that each ball has—whether associated with the ball’s motion, the ball’s position above the ground, or the ball’s loss of mechanical energy due to friction—varies in a way that keeps the total energy of the system constant.

**WHAT TO EXPECT**

In this chapter, you will learn about work and different types of energy that are relevant to mechanics. Kinetic energy, which is associated with motion, and potential energy, which is related to an object’s position, are two forms of energy that you will study.

**WHY IT MATTERS**

Work, energy, and power are related to one another. Everyday machines such as motors are usually described by the amount of work that they are capable of doing or by the amount of power that they produce.

**CHAPTER PREVIEW**

1 Work
   Definition of Work
2 Energy
   - Kinetic Energy
   - Potential Energy
3 Conservation of Energy
   - Conserved Quantities
   - Mechanical Energy
4 Power
   - Rate of Energy Transfer

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**Tapping Prior Knowledge**

**Knowledge to Expect**

✔ “Students learn that energy cannot be created or destroyed, but only changed from one form to another.” (AAAS’s *Benchmarks for Science Literacy*, grades 6–8)

✔ “Energy is associated with heat, light, electricity, mechanical motion, sound, and the nature of a chemical. Energy is transferred in many ways.” (NRC’s *National Science Education Standards*, grades 5–8)

✔ “Students tend to (a) associate energy with living things; (b) believe that energy is a fuel-like quantity; (c) think that energy transformations involve only one form of energy at a time.” (AAAS’s *Benchmarks for Science Literacy*, The Research Base)

**Knowledge to Review**

✔ Review the kinematic equations.

✔ Newton’s second law states that force = mass × acceleration (\( F = ma \)).

✔ Kinetic friction is a resistive force exerted on a moving body by its environment.

**Items to Probe**

✔ Familiarity with phenomena of energy transformation: Ask students to describe the action of jumping up and down on a trampoline in terms of energy.

✔ Preconceptions about energy dissipation: Ask students if energy is ever lost in a process.
DEFINITION OF WORK

Many of the terms you have encountered so far in this book have meanings in physics that are similar to their meanings in everyday life. In its everyday sense, the term *work* means to do something that takes physical or mental effort. But in physics, work has a distinctly different meaning. Consider the following situations:

- A student holds a heavy chair at arm’s length for several minutes.
- A student carries a bucket of water along a horizontal path while walking at constant velocity.

It might surprise you to know that as the term work is used in physics, there is no work done on the chair or the bucket, even though effort is required in both cases. We will return to these examples later.

**Work is done on an object when a force causes a displacement of the object**

Imagine that your car, like the car shown in Figure 1, has run out of gas and you have to push it down the road to the gas station. If you push the car with a constant horizontal force, the work you do on the car is equal to the magnitude of the force, *F*, times the magnitude of the displacement of the car. Using the symbol *d* instead of Δx for displacement, we define work for a constant force as:

\[ W = Fd \]

Work is not done on an object unless the object is moved with the action of a force. The application of a force alone does not constitute work. For this reason, no work is done on the chair when a student holds the chair at arm’s length. Even though the student exerts a force to support the chair, the chair does not move. The student’s tired arms suggest that work is being done, which is indeed true. The quivering muscles in the student’s arms go through many small displacements and do work within the student’s body. However, work is not done on the chair.

**Work is done only when components of a force are parallel to a displacement**

When the force on an object and the object’s displacement are in different directions, only the component of the force that is parallel to the object’s displacement does work. Components of the force perpendicular to a displacement do not do work.
For example, imagine pushing a crate along the ground. If the force you exert is horizontal, all of your effort moves the crate. If your force is at an angle, only the horizontal component of your applied force causes a displacement and contributes to the work. If the angle between the force and the direction of the displacement is $\theta$, as in Figure 2, work can be expressed as follows:

$$W = Fd \cos \theta$$

If $\theta = 0^\circ$, then $\cos 0^\circ = 1$ and $W = Fd$, which is the definition of work given earlier. If $\theta = 90^\circ$, however, then $\cos 90^\circ = 0$ and $W = 0$. So, no work is done on a bucket of water being carried by a student walking horizontally. The upward force exerted by the student to support the bucket is perpendicular to the displacement of the bucket, which results in no work done on the bucket.

Finally, if many constant forces are acting on an object, you can find the net work done on the object by first finding the net force on the object.

**NET WORK DONE BY A CONSTANT NET FORCE**

$$W_{net} = F_{net}d \cos \theta$$

net work = net force $\times$ displacement $\times$ cosine of the angle between them

Work has dimensions of force times length. In the SI system, work has a unit of newtons times meters ($N \cdot m$), or joules (J). To give you an idea of how large a joule is, consider that the work done in lifting an apple from your waist to the top of your head is about 1 J.

**SAMPLE PROBLEM A**

**Work**

**Problem**

How much work is done on a vacuum cleaner pulled 3.0 m by a force of 50.0 N at an angle of 30.0° above the horizontal?

**Solution**

Given: $F = 50.0 \text{ N}$  $\theta = 30.0^\circ$  $d = 3.0 \text{ m}$

Unknown: $W =$ ?

Use the equation for net work done by a constant force:

$$W = Fd \cos \theta$$

Only the horizontal component of the applied force is doing work on the vacuum cleaner.

$$W = (50.0 \text{ N})(3.0 \text{ m})(\cos 30.0^\circ)$$

$$W = 130 \text{ J}$$


**SECTION 1**

**ANSWERS**

Practice A

1. \(1.50 \times 10^7 \text{ J}\)
2. \(7.0 \times 10^2 \text{ J}\)
3. \(1.6 \times 10^3 \text{ J}\)
4. \(1.1 \text{ m}\)

**Demonstration**

**Quantifying Work**

**Purpose** Demonstrate the relationship between the direction and the magnitude of a force.

**Materials** plastic sled or piece of cardboard, 3 m and 1 m lengths of rope

**Procedure** Attach both ropes to the sled, and ask a student volunteer to sit on the sled. Ask students whether it will require more force to pull the sled across the floor with the 1 m rope or with the 3 m rope. *(The 3 m rope will require less force.)* Have a student try to pull the sled with each rope and report to the class which way is easier. Sketch both situations on the board, emphasizing that the horizontal component of the force is smaller with the short rope because it is held at a greater angle above the horizontal.

**Module 5**

“Work” provides an interactive lesson with guided problem-solving practice to teach you about calculating net work.

**Integrating Biology**

Visit [go.hrw.com](http://go.hrw.com) for the activity “Muscles and Work.”

**Keyword** HF6WRKX

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**The sign of work is important**

Work is a scalar quantity and can be positive or negative, as shown in **Figure 3**. Work is positive when the component of force is in the same direction as the displacement. For example, when you lift a box, the work done by the force you exert on the box is positive because that force is upward, in the same direction as the displacement. Work is negative when the force is in the direction
opposite the displacement. For example, the force of kinetic friction between a sliding box and the floor is opposite to the displacement of the box, so the work done by the force of friction on the box is negative. If you are very careful in applying the equation for work, your answer will have the correct sign: \( \cos \theta \) is negative for angles greater than 90° but less than 270°.

If the work done on an object results only in a change in the object’s speed, the sign of the net work on the object tells you whether the object’s speed is increasing or decreasing. If the net work is positive, the object speeds up and work is done on the object. If the net work is negative, the object slows down and work is done by the object on something else.

### SECTION REVIEW

1. For each of the following cases, indicate whether the work done on the second object in each example will have a positive or a negative value.
   a. The road exerts a friction force on a speeding car skidding to a stop.
   b. A rope exerts a force on a bucket as the bucket is raised up a well.
   c. Air exerts a force on a parachute as the parachutist falls to Earth.

2. If a neighbor pushes a lawnmower four times as far as you do but exerts only half the force, which one of you does more work and by how much?

3. A worker pushes a 1.50 \( \times \) 10\(^3\) N crate with a horizontal force of 345 N a distance of 24.0 m. Assume the coefficient of kinetic friction between the crate and the floor is 0.220.
   a. How much work is done by the worker on the crate?
   b. How much work is done by the floor on the crate?
   c. What is the net work done on the crate?

4. A 0.075 kg ball in a kinetic sculpture moves at a constant speed along a motorized vertical conveyor belt. The ball rises 1.32 m above the ground. A constant frictional force of 0.350 N acts in the direction opposite the conveyor belt’s motion. What is the net work done on the ball?

5. **Critical Thinking** For each of the following statements, identify whether the everyday or the scientific meaning of work is intended.
   a. Jack had to work against time as the deadline neared.
   b. Jill had to work on her homework before she went to bed.
   c. Jack did work carrying the pail of water up the hill.

6. **Critical Thinking** Determine whether work is being done in each of the following examples:
   a. a train engine pulling a loaded boxcar initially at rest
   b. a tug of war that is evenly matched
   c. a crane lifting a car

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### SECTION REVIEW ANSWERS

1. a. negative  
   b. positive  
   c. negative

2. the neighbor; twice as much

3. a. \(8.28 \times 10^3\) J  
   b. \(-7.92 \times 10^3\) J  
   c. \(3.6 \times 10^2\) J

4. 0.00 J

5. a. everyday sense  
   b. everyday sense  
   c. scientific sense

6. a. yes  
   b. no  
   c. yes
Energy

SECTION OBJECTIVES
- Identify several forms of energy.
- Calculate kinetic energy for an object.
- Apply the work–kinetic energy theorem to solve problems.
- Distinguish between kinetic and potential energy.
- Classify different types of potential energy.
- Calculate the potential energy associated with an object’s position.

KINETIC ENERGY

Kinetic energy is energy associated with an object in motion. Figure 4 shows a cart of mass $m$ moving to the right on a frictionless air track under the action of a constant net force, $F$, acting to the right. Because the force is constant, we know from Newton’s second law that the cart moves with a constant acceleration, $a$. While the force is applied, the cart accelerates from an initial velocity $v_i$ to a final velocity $v_f$. If the cart is displaced a distance of $\Delta x$, the work done by $F$ during this displacement is

$$W_{\text{net}} = F \Delta x = ma \Delta x$$

When you studied one-dimensional motion, you learned that the following relationship holds when an object undergoes constant acceleration:

$$v_f^2 = v_i^2 + 2a \Delta x$$

$$a \Delta x = \frac{v_f^2 - v_i^2}{2}$$

Substituting this result into the equation $W_{\text{net}} = ma \Delta x$ gives

$$W_{\text{net}} = m \left( \frac{v_f^2 - v_i^2}{2} \right)$$

$$W_{\text{net}} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

Kinetic energy depends on speed and mass

The quantity $\frac{1}{2}mv^2$ has a special name in physics: kinetic energy. The kinetic energy of an object with mass $m$ and speed $v$, when treated as a particle, is given by the expression shown on the next page.
Kinetic energy is a scalar quantity, and the SI unit for kinetic energy (and all other forms of energy) is the joule. Recall that a joule is also used as the basic unit for work.

Kinetic energy depends on both an object’s speed and its mass. If a bowling ball and a volleyball are traveling at the same speed, which do you think has more kinetic energy? You may think that because they are moving with identical speeds they have exactly the same kinetic energy. However, the bowling ball has more kinetic energy than the volleyball traveling at the same speed because the bowling ball has more mass than the volleyball.

**SAMPLE PROBLEM B**

**Kinetic Energy**

**Problem**

A 7.00 kg bowling ball moves at 3.00 m/s. How fast must a 2.45 g table-tennis ball move in order to have the same kinetic energy as the bowling ball? Is this speed reasonable for a table-tennis ball in play?

**Solution**

Given: The subscripts \( b \) and \( t \) indicate the bowling ball and the table-tennis ball, respectively.

\[
\begin{align*}
    m_b &= 7.00 \text{ kg} \\
    m_t &= 2.45 \text{ g} \\
    v_b &= 3.00 \text{ m/s}
\end{align*}
\]

Unknown: \( v_t = ? \)

First, calculate the kinetic energy of the bowling ball.

\[
    KE_b = \frac{1}{2} m_b v_b^2 = \frac{1}{2} (7.00 \text{ kg})(3.00 \text{ m/s})^2 = 31.5 \text{ J}
\]

Then, solve for the speed of the table-tennis ball having the same kinetic energy as the bowling ball.

\[
    KE_t = \frac{1}{2} m_t v_t^2 = KE_b = 31.5 \text{ J}
\]

\[
    v_t = \sqrt{\frac{2KE_b}{m_t}} = \sqrt{\frac{(2)(31.5 \text{ J})}{2.45 \times 10^{-3} \text{ kg}}} \approx 1.60 \times 10^2 \text{ m/s}
\]

This speed would be very fast for a table-tennis ball.
The net work done on a body equals its change in kinetic energy

The equation \( W_{\text{net}} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 \) derived at the beginning of this section says that the net work done by a net force acting on an object is equal to the change in the kinetic energy of the object. This important relationship, known as the **work–kinetic energy theorem**, is often written as follows:

**WORK–KINETIC ENERGY THEOREM**

\[
W_{\text{net}} = \Delta KE
\]

net work = change in kinetic energy

When you use this theorem, you must include all the forces that do work on the object in calculating the net work done. From this theorem, we see that the speed of the object increases if the net work done on it is positive, because the final kinetic energy is greater than the initial kinetic energy. The object’s speed decreases if the net work is negative, because the final kinetic energy is less than the initial kinetic energy.

The work–kinetic energy theorem allows us to think of kinetic energy as the work that an object can do while the object changes speed or as the amount of energy stored in the motion of an object. For example, the moving hammer in the ring-the-bell game in Figure 5 has kinetic energy and can therefore do work on the puck. The puck can do work against gravity by moving up and striking the bell. When the bell is struck, part of the energy is converted into sound.

**Figure 5**
The moving hammer has kinetic energy and can do work on the puck, which can rise against gravity and ring the bell.
Work–Kinetic Energy Theorem

Problem
On a frozen pond, a person kicks a 10.0 kg sled, giving it an initial speed of 2.2 m/s. How far does the sled move if the coefficient of kinetic friction between the sled and the ice is 0.10?

Solution

1. Define
Given:
- \( m = 10.0 \text{ kg} \)
- \( v_i = 2.2 \text{ m/s} \)
- \( v_f = 0 \text{ m/s} \)
- \( \mu_k = 0.10 \)

Unknown:
- \( d = ? \)

Diagram:

2. Plan
Choose an equation or situation:
This problem can be solved using the definition of work and the work–kinetic energy theorem.

\[ W_{\text{net}} = F_{\text{net}} d \cos \theta \]

The net work done on the sled is provided by the force of kinetic friction.

\[ W_{\text{net}} = F_k d \cos \theta = \mu_k mg d \cos \theta \]

The force of kinetic friction is in the direction opposite \( d \), so \( \theta = 180^\circ \).

Because the sled comes to rest, the final kinetic energy is zero.

\[ W_{\text{net}} = \Delta KE = KE_f - KE_i = -\frac{1}{2} mv_i^2 \]

Use the work-kinetic energy theorem, and solve for \( d \).

\[ -\frac{1}{2} mv_i^2 = \mu_k mg d \cos \theta \]

\[ d = \frac{-v_i^2}{2 \mu_k g \cos \theta} \]

3. Calculate
Substitute values into the equation:

\[ d = \frac{-(2.2 \text{ m/s})^2}{2(0.10)(9.81 \text{ m/s}^2)(\cos 180^\circ)} \]

\[ d = 2.5 \text{ m} \]

4. Evaluate
According to Newton’s second law, the acceleration of the sled is about \(-1 \text{ m/s}^2 \)
and the time it takes the sled to stop is about 2 s. Thus, the distance the sled traveled in the given amount of time should be less than the distance it would have traveled in the absence of friction.

\[ 2.5 \text{ m} < (2.2 \text{ m/s})(2 \text{ s}) = 4.4 \text{ m} \]
Section 2

Answers

Practice C
1. 7.8 m
2. 21 m
3. 5.1 m
4. $3.0 \times 10^2$ N

Practice C

Work–Kinetic Energy Theorem

1. A student wearing frictionless in-line skates on a horizontal surface is pushed by a friend with a constant force of 45 N. How far must the student be pushed, starting from rest, so that her final kinetic energy is 352 J?

2. A $2.0 \times 10^3$ kg car accelerates from rest under the actions of two forces. One is a forward force of 1140 N provided by traction between the wheels and the road. The other is a 950 N resistive force due to various frictional forces. Use the work–kinetic energy theorem to determine how far the car must travel for its speed to reach 2.0 m/s.

3. A $2.1 \times 10^3$ kg car starts from rest at the top of a driveway that is sloped at an angle of 20.0° with the horizontal. An average friction force of $4.0 \times 10^3$ N impedes the car's motion so that the car's speed at the bottom of the driveway is 3.8 m/s. What is the length of the driveway?

4. A 75 kg bobsled is pushed along a horizontal surface by two athletes. After the bobsled is pushed a distance of 4.5 m starting from rest, its speed is 6.0 m/s. Find the magnitude of the net force on the bobsled.

The Inside Story on the Energy in Food

The food that you eat provides your body with energy. Your body needs this energy to move your muscles, to maintain a steady internal temperature, and to carry out many other bodily processes. The energy in food is stored as a kind of potential energy in the chemical bonds within sugars and other organic molecules.

When you digest food, some of this energy is released. The energy is then stored again in sugar molecules, usually as glucose. When cells in your body need energy to carry out cellular processes, the cells break down the glucose molecules through a process called cellular respiration. The primary product of cellular respiration is a high-energy molecule called adenosine triphosphate (ATP), which has a significant role in many chemical reactions in cells.

Nutritionists and food scientists use units of Calories to quantify the energy in food. A standard calorie (cal) is defined as the amount of energy required to increase the temperature of 1 mL of water by 1°C, which equals 4.186 joules (J). A food Calorie is actually 1 kilocalorie, or 4186 J.

People who are trying to lose weight often monitor the number of Calories that they eat each day. These people count Calories because the body stores unused energy as fat. Most food labels show the number of Calories in each serving of food. The amount of energy that your body needs each day depends on many factors, including your age, your weight, and the amount of exercise that you get. A typically healthy and active person requires about 1500 to 2000 Calories per day.
POTENTIAL ENERGY

Consider the balanced boulder shown in Figure 6. As long as the boulder remains balanced, it has no kinetic energy. If it becomes unbalanced, it will fall vertically to the desert floor and will gain kinetic energy as it falls. A similar example is an arrow ready to be released on a bent bow. Once the arrow is in flight, it will have kinetic energy.

Potential energy is stored energy

As we have seen, an object in motion has kinetic energy. But a system can have other forms of energy. The examples above describe a form of energy that is due to the position of an object in relation to other objects or to a reference point. Potential energy is associated with an object that has the potential to move because of its position relative to some other location. Unlike kinetic energy, potential energy depends not only on the properties of an object but also on the object’s interaction with its environment.

Gravitational potential energy depends on height from a zero level

You learned earlier how gravitational forces influence the motion of a projectile. If an object is thrown up in the air, the force of gravity will eventually cause the object to fall back down, provided that the object was not thrown too hard. Similarly, the force of gravity will cause the unbalanced boulder in the previous example to fall. The energy associated with an object due to the object’s position relative to a gravitational source is called gravitational potential energy.

Imagine an egg falling off a table. As it falls, it gains kinetic energy. But where does the egg’s kinetic energy come from? It comes from the gravitational potential energy that is associated with the egg’s initial position on the table relative to the floor. Gravitational potential energy can be determined using the following equation:

\[ PE_g = mgh \]

gravitational potential energy = mass \times free-fall acceleration \times height

The SI unit for gravitational potential energy, like for kinetic energy, is the joule. Note that the definition for gravitational potential energy in this chapter is valid only when the free-fall acceleration is constant over the entire height, such as at any point near the Earth’s surface. Furthermore, gravitational potential energy depends on both the height and the free-fall acceleration, neither of which is a property of an object.
SECTION 2

Misconception Alert

Some students do not realize that the potential energy of an object is relative. Point out that the zero-level for measuring height is arbitrarily defined in each problem. The potential energy is calculated relative to that level. Ask students how they would calculate the potential energy of a book on their desk relative to the desk, to the classroom floor, and to the roof.

Teaching Tip

Ask students whether it is possible to have a negative potential energy. (Yes, a negative potential energy means that work must be done to bring an object to the zero-level.) Then ask whether an object can have a positive potential energy relative to one reference point and a negative potential energy relative to another reference point. Have students give examples to support their answer. (Yes. For example, a book that is 0.5 m below a table and 0.5 m above the ground has a positive potential energy relative to the ground but a negative potential energy relative to the table.)

Visual Strategy

Point out that the spring’s potential energy depends on the difference between the spring’s relaxed and compressed lengths.

Elastic potential energy

The energy available for use when a deformed elastic object returns to its original configuration.

Sprung constant

A parameter that is a measure of a spring’s resistance to being compressed or stretched.

Elastic potential energy depends on distance compressed or stretched

Suppose you drop a volleyball from a second-floor roof and it lands on the first-floor roof of an adjacent building (see Figure 7). If the height is measured from the ground, the gravitational potential energy is not zero because the ball is still above the ground. But if the height is measured from the first-floor roof, the potential energy is zero when the ball lands on the roof.

Gravitational potential energy is a result of an object’s position, so it must be measured relative to some zero level. The zero level is the vertical coordinate at which gravitational potential energy is defined to be zero. This zero level is arbitrary, and it is chosen to make a specific problem easier to solve. In many cases, the statement of the problem suggests what to use as a zero level.

Elastic potential energy is stored in any compressed or stretched object, such as a spring or the stretched strings of a tennis racket or guitar.

The length of a spring when no external forces are acting on it is called the relaxed length of the spring. When an external force compresses or stretches the spring, elastic potential energy is stored in the spring. The amount of energy depends on the distance the spring is compressed or stretched from its relaxed length, as shown in Figure 8. Elastic potential energy can be determined using the following equation:

\[ \text{Elastic Potential Energy} = \frac{1}{2} kx^2 \]

The symbol \( k \) is called the spring constant, or force constant. For a flexible spring, the spring constant is small, whereas for a stiff spring, the spring constant is large. Spring constants have units of newtons divided by meters (N/m).
SAMPLE PROBLEM D

Potential Energy

PROBLEM

A 70.0 kg stuntman is attached to a bungee cord with an unstretched length of 15.0 m. He jumps off a bridge spanning a river from a height of 50.0 m. When he finally stops, the cord has a stretched length of 44.0 m. Treat the stuntman as a point mass, and disregard the weight of the bungee cord. Assuming the spring constant of the bungee cord is 71.8 N/m, what is the total potential energy relative to the water when the man stops falling?

SOLUTION

Given:

\[ m = 70.0 \text{ kg} \quad k = 71.8 \text{ N/m} \quad g = 9.81 \text{ m/s}^2 \]
\[ h = 50.0 \text{ m} - 44.0 \text{ m} = 6.0 \text{ m} \]
\[ x = 44.0 \text{ m} - 15.0 \text{ m} = 29.0 \text{ m} \]
\[ PE = 0 \text{ J at river level} \]

Unknown:

\[ PE_{tot} = ? \]

Diagram:

Choose an equation or situation:

The zero level for gravitational potential energy is chosen to be at the surface of the water. The total potential energy is the sum of the gravitational and elastic potential energy.

\[ PE_{tot} = PE_g + PE_{elastic} \]
\[ PE_g = mgh \]
\[ PE_{elastic} = \frac{1}{2}kx^2 \]

Substitute the values into the equations and solve:

\[ PE_g = (70.0 \text{ kg})(9.81 \text{ m/s}^2)(6.0 \text{ m}) = 4.1 \times 10^3 \text{ J} \]
\[ PE_{elastic} = \frac{1}{2}(71.8 \text{ N/m})(29.0 \text{ m})^2 = 3.02 \times 10^4 \text{ J} \]
\[ PE_{tot} = 4.1 \times 10^3 \text{ J} + 3.02 \times 10^4 \text{ J} \]
\[ PE_{tot} = 3.43 \times 10^4 \text{ J} \]

One way to evaluate the answer is to make an order-of-magnitude estimate. The gravitational potential energy is on the order of \( 10^2 \text{ kg} \times 10 \text{ m/s}^2 \times 10 \text{ m} = 10^4 \text{ J} \). The elastic potential energy is on the order of \( 1 \times 10^2 \text{ N/m} \times 10^2 \text{ m}^2 = 10^4 \text{ J} \). Thus, the total potential energy should be on the order of \( 2 \times 10^4 \text{ J} \). This number is close to the actual answer.
### Potential Energy

1. A spring with a force constant of 5.2 N/m has a relaxed length of 2.45 m. When a mass is attached to the end of the spring and allowed to come to rest, the vertical length of the spring is 3.57 m. Calculate the elastic potential energy stored in the spring.

2. The staples inside a stapler are kept in place by a spring with a relaxed length of 0.115 m. If the spring constant is 51.0 N/m, how much elastic potential energy is stored in the spring when its length is 0.150 m?

3. A 40.0 kg child is in a swing that is attached to ropes 2.00 m long. Find the gravitational potential energy associated with the child relative to the child’s lowest position under the following conditions:
   a. when the ropes are horizontal
   b. when the ropes make a 30.0° angle with the vertical
   c. at the bottom of the circular arc

### Section Review Answers

1. $4.4 \times 10^{-3}$ J
2. 2.8 m/s
3. $6.18 \times 10^{-2}$ J
4. a. kinetic energy
   b. nonmechanical energy
   c. kinetic energy, gravitational potential energy
   d. elastic potential energy
5. The heated water is an instance of nonmechanical energy, because its mass is not displaced with a velocity or with respect to a zero position, as would be the case for the various types of mechanical energy. The bicycle and football both have masses in motion, so they have kinetic energy. The wound spring has been displaced from its relaxed position and so has elastic potential energy, while the football is above the ground and therefore has a gravitational potential energy associated with it.

1. A pinball bangs against a bumper, giving the ball a speed of 42 cm/s. If the ball has a mass of 50.0 g, what is the ball’s kinetic energy in joules?

2. A student slides a 0.75 kg textbook across a table, and it comes to rest after traveling 1.2 m. Given that the coefficient of kinetic friction between the book and the table is 0.34, use the work–kinetic energy theorem to find the book’s initial speed.

3. A spoon is raised 21.0 cm above a table. If the spoon and its contents have a mass of 30.0 g, what is the gravitational potential energy associated with the spoon at that height relative to the surface of the table?

4. **Critical Thinking** What forms of energy are involved in the following situations?
   a. a bicycle coasting along a level road
   b. heating water
   c. throwing a football
   d. winding the mainspring of a clock

5. **Critical Thinking** How do the forms of energy in item 4 differ from one another? Be sure to discuss mechanical versus nonmechanical energy, kinetic versus potential energy, and gravitational versus elastic potential energy.
Conservation of Energy

CONSERVED QUANTITIES

When we say that something is conserved, we mean that it remains constant. If we have a certain amount of a conserved quantity at some instant of time, we will have the same amount of that quantity at a later time. This does not mean that the quantity cannot change form during that time, but if we consider all the forms that the quantity can take, we will find that we always have the same amount.

For example, the amount of money you now have is not a conserved quantity because it is likely to change over time. For the moment, however, let us assume that you do not spend the money you have, so your money is conserved. This means that if you have a dollar in your pocket, you will always have that same amount, although it may change form. One day it may be in the form of a bill. The next day you may have a hundred pennies, and the next day you may have an assortment of dimes and nickels. But when you total the change, you always have the equivalent of a dollar. It would be nice if money were like this, but of course it isn’t. Because money is often acquired and spent, it is not a conserved quantity.

An example of a conserved quantity that you are already familiar with is mass. For instance, imagine that a light bulb is dropped on the floor and shatters into many pieces. No matter how the bulb shatters, the total mass of all of the pieces together is the same as the mass of the intact light bulb because mass is conserved.

MECHANICAL ENERGY

We have seen examples of objects that have either kinetic or potential energy. The description of the motion of many objects, however, often involves a combination of kinetic and potential energy as well as different forms of potential energy. Situations involving a combination of these different forms of energy can often be analyzed simply. For example, consider the motion of the different parts of a pendulum clock. The pendulum swings back and forth. At the highest point of its swing, there is only gravitational potential energy associated with its position. At other points in its swing, the pendulum is in motion, so it has kinetic energy as well. Elastic potential energy is also present in the many springs that are part of the inner workings of the clock. The motion of the pendulum in a clock is shown in Figure 9.

Figure 9
Total potential and kinetic energy must be taken into account in order to describe the total energy of the pendulum in a clock.
Analyzing situations involving kinetic, gravitational potential, and elastic potential energy is relatively simple. Unfortunately, analyzing situations involving other forms of energy—such as chemical potential energy—is not as easy.

We can ignore these other forms of energy if their influence is negligible or if they are not relevant to the situation being analyzed. In most situations that we are concerned with, these forms of energy are not involved in the motion of objects. In ignoring these other forms of energy, we will find it useful to define a quantity called mechanical energy. The mechanical energy is the sum of kinetic energy and all forms of potential energy associated with an object or group of objects.

\[ ME = KE + \Sigma PE \]

All energy, such as nuclear, chemical, internal, and electrical, that is not mechanical energy is classified as nonmechanical energy. Do not be confused by the term mechanical energy. It is not a unique form of energy. It is merely a way of classifying energy, as shown in Figure 10. As you learn about new forms of energy in this book, you will be able to add them to this chart.

### Mechanical energy is often conserved

Imagine a 75 g egg located on a countertop 1.0 m above the ground, as shown in Figure 11. The egg is knocked off the edge and falls to the ground. Because the acceleration of the egg is constant as it falls, you can use the kinematic formulas to determine the speed of the egg and the distance the egg has fallen at any subsequent time. The distance fallen can then be subtracted from the initial height to find the height of the egg above the ground at any subsequent time. For example, after 0.10 s, the egg has a speed of 0.98 m/s and has fallen a distance of 0.05 m, corresponding to a height above the ground of 0.95 m. Once the egg’s speed and its height above the ground are known as a function of time, you can use what you have learned in this chapter to calculate both the kinetic energy of the egg and the gravitational potential energy associated with the position of the egg at any subsequent time. Adding the kinetic and potential energy gives the total mechanical energy at each position.
In the absence of friction, the total mechanical energy remains the same. This principle is called conservation of mechanical energy. Although the amount of mechanical energy is constant, mechanical energy itself can change form. For instance, consider the forms of energy for the falling egg, as shown in Table 1. As the egg falls, the potential energy is continuously converted into kinetic energy. If the egg were thrown up in the air, kinetic energy would be converted into gravitational potential energy. In either case, mechanical energy is conserved. The conservation of mechanical energy can be written symbolically as follows:

\[ ME_i = ME_f \]

**CONSERVATION OF MECHANICAL ENERGY**

\[ initial \ mechanical \ energy = final \ mechanical \ energy \]

\[ (in \ the \ absence \ of \ friction) \]

The mathematical expression for the conservation of mechanical energy depends on the forms of potential energy in a given problem. For instance, if the only force acting on an object is the force of gravity, as in the egg example, the conservation law can be written as follows:

\[ \frac{1}{2}mv_i^2 + mgh_i = \frac{1}{2}mv_f^2 + mgh_f \]

If other forces (except friction) are present, simply add the appropriate potential energy terms associated with each force. For instance, if the egg happened to compress or stretch a spring as it fell, the conservation law would also include an elastic potential energy term on each side of the equation.

In situations in which frictional forces are present, the principle of mechanical energy conservation no longer holds because kinetic energy is not simply converted to a form of potential energy. This special situation will be discussed more thoroughly later in this section.
**SAMPLE PROBLEM E**

**Conservation of Mechanical Energy**

**PROBLEM**

Starting from rest, a child zooms down a frictionless slide from an initial height of 3.00 m. What is her speed at the bottom of the slide? Assume she has a mass of 25.0 kg.

**SOLUTION**

**1. DEFINE**

- **Given:**
  - \( h = h_i = 3.00 \text{ m} \)
  - \( m = 25.0 \text{ kg} \)
  - \( v_i = 0.0 \text{ m/s} \)
  - \( h_f = 0 \text{ m} \)

- **Unknown:**
  - \( v_f = ? \)

**2. PLAN**

**Choose an equation or situation:**

The slide is frictionless, so mechanical energy is conserved. Kinetic energy and gravitational potential energy are the only forms of energy present.

\[ KE = \frac{1}{2}mv^2 \quad PE = mgh \]

The zero level chosen for gravitational potential energy is the bottom of the slide. Because the child ends at the zero level, the final gravitational potential energy is zero.

\[ PE_{g,f} = 0 \]

The initial gravitational potential energy at the top of the slide is

\[ PE_{g,i} = mgh_i = mgh \]

Because the child starts at rest, the initial kinetic energy at the top is zero.

\[ KE_i = 0 \]

Therefore, the final kinetic energy is as follows:

\[ KE_f = \frac{1}{2}mv_f^2 \]

**3. CALCULATE**

**Substitute values into the equations:**

\[ PE_{g,i} = (25.0 \text{ kg})(9.81 \text{ m/s}^2)(3.00 \text{ m}) = 736 \text{ J} \]

\[ KE_f = \left(\frac{1}{2}\right)(25.0 \text{ kg})v_f^2 \]

Now use the calculated quantities to evaluate the final velocity.

\[ ME_i = ME_f \]

\[ PE_i + KE_i = PE_f + KE_f \]

\[ 736 \text{ J} + 0 \text{ J} = 0 \text{ J} + (0.500)(25.0 \text{ kg})v_f^2 \]

\[ v_f = 7.67 \text{ m/s} \]

**CALCULATOR SOLUTION**

Your calculator should give an answer of 7.67333, but because the answer is limited to three significant figures, it should be rounded to 7.67.
The expression for the square of the final speed can be written as follows:

\[ v_f^2 = \frac{2mgh}{m} = 2gh \]

Notice that the masses cancel, so the final speed does not depend on the mass of the child. This result makes sense because the acceleration of an object due to gravity does not depend on the mass of the object.

PRACTICE E

Conservation of Mechanical Energy

1. A bird is flying with a speed of 18.0 m/s over water when it accidentally drops a 2.00 kg fish. If the altitude of the bird is 5.40 m and friction is disregarded, what is the speed of the fish when it hits the water?

2. A 755 N diver drops from a board 10.0 m above the water’s surface. Find the diver’s speed 5.00 m above the water’s surface. Then find the diver’s speed just before striking the water.

3. If the diver in item 2 leaves the board with an initial upward speed of 2.00 m/s, find the diver’s speed when striking the water.

4. An Olympic runner leaps over a hurdle. If the runner’s initial vertical speed is 2.2 m/s, how much will the runner’s center of mass be raised during the jump?

5. A pendulum bob is released from some initial height such that the speed of the bob at the bottom of the swing is 1.9 m/s. What is the initial height of the bob?

Energy conservation occurs even when acceleration varies

If the slope of the slide in Sample Problem E was constant, the acceleration along the slide would also be constant and the one-dimensional kinematic formulas could have been used to solve the problem. However, you do not know the shape of the slide. Thus, the acceleration may not be constant, and the kinematic formulas could not be used.

But now we can apply a new method to solve such a problem. Because the slide is frictionless, mechanical energy is conserved. We simply equate the initial mechanical energy to the final mechanical energy and ignore all the details in the middle. The shape of the slide is not a contributing factor to the system’s mechanical energy as long as friction can be ignored.
Mechanical energy is not conserved in the presence of friction

If you have ever used a sanding block to sand a rough surface, such as in Figure 12, you may have noticed that you had to keep applying a force to keep the block moving. The reason is that kinetic friction between the moving block and the surface causes the kinetic energy of the block to be converted into a nonmechanical form of energy. As you continue to exert a force on the block, you are replacing the kinetic energy that is lost because of kinetic friction. The observable result of this energy dissipation is that the sanding block and the tabletop become warmer.

In the presence of kinetic friction, nonmechanical energy is no longer negligible and mechanical energy is no longer conserved. This does not mean that energy in general is not conserved—total energy is always conserved. However, the mechanical energy is converted into forms of energy that are much more difficult to account for, and the mechanical energy is therefore considered to be “lost.”

Some students may confuse the conservation of mechanical energy with the general energy conservation law. Point out that although mechanical energy is not always conserved, the total energy is always conserved. For example, as the sanding block’s kinetic energy decreases, energy is transferred to the rough surface in the form of internal energy (this topic will be discussed in the chapter on heat and temperature). As a result, the temperatures of the block and surface increase slightly. The total energy in the system remains constant, although the mechanical energy decreases.

### SECTION REVIEW

1. 2.93 m/s
2. No, the roller coaster will not reach the top of the second hill. If the total mechanical energy is constant, the roller coaster will reach its initial height and then begin rolling back down the hill.
3. a. yes
   b. no
   c. yes, if air resistance is disregarded
4. Answers may vary. The downward-sloping track converts potential energy to kinetic energy. Levers employ kinetic energy to increase potential energy. Springs and elastic membranes convert kinetic energy to elastic potential energy and back again. Mechanical energy is not conserved; some energy is lost because of kinetic friction.

### Answers

1. If the spring of a jack-in-the-box is compressed a distance of 8.00 cm from its relaxed length and then released, what is the speed of the toy head when the spring returns to its natural length? Assume the mass of the toy head is 50.0 g, the spring constant is 80.0 N/m, and the toy head moves only in the vertical direction. Also disregard the mass of the spring. (Hint: Remember that there are two forms of potential energy in the problem.)

2. You are designing a roller coaster in which a car will be pulled to the top of a hill of height \( h \) and then, starting from a momentary rest, will be released to roll freely down the hill and toward the peak of the next hill, which is 1.1 times as high. Will your design be successful? Explain your answer.

3. Is conservation of mechanical energy likely to hold in these situations?
   a. a hockey puck sliding on a frictionless surface of ice
   b. a toy car rolling on a carpeted floor
   c. a baseball being thrown into the air

4. Critical Thinking What parts of the kinetic sculpture on the opening pages of this chapter involve the conversion of one form of energy to another? Is mechanical energy conserved in these processes?
Power

**SECTION OBJECTIVES**
- Relate the concepts of energy, time, and power.
- Calculate power in two different ways.
- Explain the effect of machines on work and power.

**SECTION 4**
General Level

**Power**

**RATE OF ENERGY TRANSFER**

The rate at which work is done is called **power**. More generally, power is the rate of energy transfer by any method. Like the concepts of energy and work, power has a specific meaning in science that differs from its everyday meaning.

Imagine you are producing a play and you need to raise and lower the curtain between scenes in a specific amount of time. You decide to use a motor that will pull on a rope connected to the top of the curtain rod. Your assistant finds three motors but doesn’t know which one to use. One way to decide is to consider the power output of each motor.

If the work done on an object is \( W \) in a time interval \( \Delta t \), then the average power delivered to the object over this time interval is written as follows:

\[
P = \frac{W}{\Delta t}
\]

**POWER**

\[
\text{power} = \text{work} \div \text{time interval}
\]

It is sometimes useful to rewrite this equation in an alternative form by substituting the definition of work into the definition of power.

\[
W = Fd
\]

\[
P = \frac{W}{\Delta t} = \frac{F \cdot d}{\Delta t}
\]

The distance moved per unit time is just the speed of the object.

**Teaching Tip**

To help students understand the relationship \( P = Fv \), have them calculate power both ways in a simple example. For example, ask students to calculate the work done, the power using the first equation, the speed, and the power using the second equation when a 100.0 N force moves an object 20.0 m in 5.0 s at constant speed (\( 2.00 \times 10^3 \) J, \( 4.0 \times 10^2 \) W, \( 4.0 \) m/s, \( 4.0 \times 10^2 \) W).

**ANSWERS**

**Conceptual Challenge**

1. **Mountain Roads**
   Many mountain roads are built so that they zigzag up the mountain rather than go straight up toward the peak. Discuss the advantages of such a design from the viewpoint of energy conservation and power.

2. **Light Bulbs**
   A light bulb is described as having 60 watts. What’s wrong with this statement?

**Integrating Chemistry**

Visit [go.hrw.com](go.hrw.com) for the activity “Chemical Reactions.”

Keyword: HF6WRKX
The SI unit of power is the *watt*, \( W \), which is defined to be one joule per second. The *horsepower*, \( \text{hp} \), is another unit of power that is sometimes used. One horsepower is equal to 746 watts.

The watt is perhaps most familiar to you from your everyday experience with light bulbs (see Figure 13). A dim light bulb uses about 40 W of power, while a bright bulb can use up to 500 W. Decorative lights use about 0.7 W each for indoor lights and 7.0 W each for outdoor lights.

In Sample Problem F, the three motors would lift the curtain at different rates because the power output for each motor is different. So each motor would do work on the curtain at different rates and would thus transfer energy to the curtain at different rates.

### POWER (ALTERNATIVE FORM)

\[
P = F \nu
\]

\[
\text{power} = \text{force} \times \text{speed}
\]

The best motor to use is the 3.5 kW motor. The 1.0 kW motor will not lift the curtain fast enough, and the 5.5 kW motor will lift the curtain too fast.
Power

1. A 1.0 × 10^3 kg elevator carries a maximum load of 800.0 kg. A constant frictional force of 4.0 × 10^3 N retards the elevator’s motion upward. What minimum power, in kilowatts, must the motor deliver to lift the fully loaded elevator at a constant speed of 3.00 m/s?

2. A car with a mass of 1.50 × 10^3 kg starts from rest and accelerates to a speed of 18.0 m/s in 12.0 s. Assume that the force of resistance remains constant at 400.0 N during this time. What is the average power developed by the car’s engine?

3. A rain cloud contains 2.66 × 10^7 kg of water vapor. How long would it take for a 2.00 kW pump to raise the same amount of water to the cloud’s altitude, 2.00 km?

4. How long does it take a 19 kW steam engine to do 6.8 × 10^7 J of work?

5. A 1.50 × 10^3 kg car accelerates uniformly from rest to 10.0 m/s in 3.00 s.
   a. What is the work done on the car in this time interval?
   b. What is the power delivered by the engine in this time interval?

SECTION REVIEW

1. A 50.0 kg student climbs 5.00 m up a rope at a constant speed. If the student’s power output is 200.0 W, how long does it take the student to climb the rope? How much work does the student do?

2. A motor-driven winch pulls the 50.0 kg student in the previous item 5.00 m up the rope at a constant speed of 1.25 m/s. How much power does the motor use in raising the student? How much work does the motor do on the student?

3. Critical Thinking How are energy, time, and power related?

4. Critical Thinking People often use the word powerful to describe the engines in some automobiles. In this context, how does the word relate to the definition of power? How does this word relate to the alternative definition of power?
Roller Coaster Designer

Two of Steve’s first roller coasters are the Ninjas at Six Flags Over Mid-America and at Six Flags Magic Mountain. His West Coaster, built on Santa Monica Pier, towers five stories above the Pacific Ocean. The cars on the Steel Force at Dorney Park in Pennsylvania reach speeds of over 75 mi/h and drop more than 200 ft to disappear into a 120 ft tunnel. The Mamba at Worlds of Fun in Missouri features two giant back-to-back hills, a fast spiral, and five camelback humps. The camelbacks are designed to pull your seat out from under you, so that you feel like you’re floating. Roller coaster fans call this feeling airtime.

As the name states, the cars of a roller coaster really do coast along the tracks. A motor pulls the cars up a high hill at the beginning of the ride. After the hill, however, the motion of the car is a result of gravity and inertia. As the cars roll down the hill, they must pick up the speed that they need to whiz through the rest of the curves, loops, twists, and bumps in the track. To learn more about designing roller coasters, read the interview with Steve Okamoto.

How did you become a roller coaster designer?

I have been fascinated with roller coasters ever since my first ride on one. I remember going to Disneyland as a kid. My mother was always upset with me because I kept looking over the sides of the rides, trying to figure out how they worked. My interest in finding out how things worked led me to study mechanical engineering.

What sort of training do you have?

I earned a degree in product design. For this degree, I studied mechanical engineering and studio art. Product designers consider an object’s form as well as its function. They also take into account the interests and abilities of the product’s consumer. Most rides and parks have some kind of theme, so I must consider marketing goals and concerns in my designs.

What is the nature of your work?

To design a roller coaster, I study site maps of the location. Then, I go to the amusement park to look at the actual site. Because most rides I design are for older parks (few

parks are built from scratch), fitting a coaster around, above, and in between existing rides and buildings is one of my biggest challenges. I also have to design how the parts of the ride will work together. The towers and structures that support the ride have to be strong enough to hold up a track and speeding cars that are full of people. The cars themselves need special wheels to keep them locked onto the track and seat belts or bars to keep the passengers safely inside. It’s like putting together a puzzle, except the pieces haven’t been cut out yet.

What advice do you have for a student who is interested in designing roller coasters?

Studying math and science is very important. To design a successful coaster, I have to understand how energy is converted from one form to another as the cars move along the track. I have to calculate speeds and accelerations of the cars on each part of the track. They have to go fast enough to make it up the next hill! I rely on my knowledge of geometry and physics to create the roller coaster’s curves, loops, and dips.
KEY IDEAS

Section 1 Work
• Work is done on an object only when a net force acts on the object to displace it in the direction of a component of the net force.
• The amount of work done on an object by a force is equal to the component of the force along the direction of motion times the distance the object moves.

Section 2 Energy
• Objects in motion have kinetic energy because of their mass and speed.
• The net work done on or by an object is equal to the change in the kinetic energy of the object.
• Potential energy is energy associated with an object’s position. Two forms of potential energy discussed in this chapter are gravitational potential energy and elastic potential energy.

Section 3 Conservation of Energy
• Energy can change form but can never be created or destroyed.
• Mechanical energy is the total kinetic and potential energy present in a given situation.
• In the absence of friction, mechanical energy is conserved, so the amount of mechanical energy remains constant.

Section 4 Power
• Power is the rate at which work is done or the rate of energy transfer.
• Machines with different power ratings do the same amount of work in different time intervals.

KEY TERMS

work (p. 160)
kinetic energy (p. 164)
work–kinetic energy theorem (p. 166)
potential energy (p. 169)
gravitational potential energy (p. 169)
elastic potential energy (p. 170)
mechanical energy (p. 174)
power (p. 179)

Teaching Tip
Explaining concepts in written form helps solidify students’ understanding of difficult concepts and helps enforce good communication skills. Have students summarize the differences between mechanical and non-mechanical energy and between kinetic energy, gravitational potential energy, and elastic potential energy. Essays should also include a thorough discussion of work and its link to kinetic and potential energy. Be sure students explain concepts clearly and correctly and use good sentence structure.

Variable Symbols

<table>
<thead>
<tr>
<th>Quantities</th>
<th>Units</th>
<th>Conversions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W$ work</td>
<td>$J$ joule</td>
<td>= $N \cdot m$</td>
</tr>
<tr>
<td>$KE$ kinetic energy</td>
<td>$J$ joule</td>
<td></td>
</tr>
<tr>
<td>$PE_g$ gravitational potential energy</td>
<td>$J$ joule</td>
<td></td>
</tr>
<tr>
<td>$PE_{elastic}$ elastic potential energy</td>
<td>$J$ joule</td>
<td></td>
</tr>
<tr>
<td>$P$ power</td>
<td>$W$ watt</td>
<td>= $J/s$</td>
</tr>
</tbody>
</table>
Review

ANSWERS

1. No, a change in speed corresponds to a change in kinetic energy, which cannot occur without work (either positive or negative) being done on the object.

2. a. yes, positive
   b. no
   c. yes, positive
   d. yes, negative

3. No, force would decrease, but distance would increase, which would keep work constant.

4. The tension is perpendicular to the bob's motion, so it does not do work on the bob. The component of the bob's weight that is perpendicular to the bob's motion does not do work on the bob, but the component that is in the direction of its motion does.

5. The car leaving longer skid marks was moving faster.

6. yes; no; yes, the ball's weight and air resistance

7. $53 \text{ J}, -53 \text{ J}$

8. $2.4 \times 10^5 \text{ J}$

9. $47.5 \text{ J}$

10. a. $6230 \text{ J}$
    b. $-6230 \text{ J}$
    c. $0.640$

11. a. no
    b. yes
    c. yes

WORK

Review Questions

1. Can the speed of an object change if the net work done on it is zero?

2. Discuss whether any work is being done by each of the following agents and, if so, whether the work is positive or negative.
   a. a chicken scratching the ground
   b. a person reading a sign
   c. a crane lifting a bucket of concrete
   d. the force of gravity on the bucket in (c)

3. Furniture movers wish to load a truck using a ramp from the ground to the rear of the truck. One of the movers claims that less work would be required if the ramp’s length were increased, reducing its angle with the horizontal. Is this claim valid? Explain.

Conceptual Questions

4. A pendulum swings back and forth, as shown at right. Does the tension force in the string do work on the pendulum bob? Does the force of gravity do work on the bob? Explain your answers.

5. The drivers of two identical cars heading toward each other apply the brakes at the same instant. The skid marks of one of the cars are twice as long as the skid marks of the other vehicle. Assuming that the brakes of both cars apply the same force, what conclusions can you draw about the motion of the cars?

6. When a punter kicks a football, is he doing work on the ball while his toe is in contact with it? Is he doing work on the ball after the ball loses contact with his toe? Are any forces doing work on the ball while the ball is in flight?

Practice Problems

For problems 7–10, see Sample Problem A.

7. A person lifts a 4.5 kg cement block a vertical distance of 1.2 m and then carries the block horizontally a distance of 7.3 m. Determine the work done by the person and by the force of gravity in this process.

8. A plane designed for vertical takeoff has a mass of $8.0 \times 10^3 \text{ kg}$. Find the net work done by all forces on the plane as it accelerates upward at $1.0 \text{ m/s}^2$ through a distance of 30.0 m after starting from rest.

9. When catching a baseball, a catcher’s glove moves by 10 cm along the line of motion of the ball. If the baseball exerts a force of 475 N on the glove, how much work is done by the ball?

10. A flight attendant pulls her 70.0 N flight bag a distance of 253 m along a level airport floor at a constant velocity. The force she exerts is 40.0 N at an angle of $52.0^\circ$ above the horizontal. Find the following:
    a. the work she does on the flight bag
    b. the work done by the force of friction on the flight bag
    c. the coefficient of kinetic friction between the flight bag and the floor

ENERGY

Review Questions

11. A person drops a ball from the top of a building while another person on the ground observes the ball’s motion. Each observer chooses his or her own location as the level for zero potential energy. Will they calculate the same values for:
    a. the potential energy associated with the ball?
    b. the change in potential energy associated with the ball?
    c. the ball’s kinetic energy?
12. Can the kinetic energy of an object be negative? Explain your answer.

13. Can the gravitational potential energy associated with an object be negative? Explain your answer.

14. Two identical objects move with speeds of 5.0 m/s and 25.0 m/s. What is the ratio of their kinetic energies?

Conceptual Questions

15. A satellite is in a circular orbit above Earth’s surface. Why is the work done on the satellite by the gravitational force zero? What does the work–kinetic energy theorem predict about the satellite’s speed?

16. A car traveling at 50.0 km/h skids a distance of 35 m after its brakes lock. Estimate how far it will skid if its brakes lock when its initial speed is 100.0 km/h. What happens to the car’s kinetic energy as it comes to rest?

17. Explain why more energy is needed to walk up stairs than to walk horizontally at the same speed.

18. How can the work–kinetic energy theorem explain why the force of sliding friction reduces the kinetic energy of a particle?

Practice Problems

For problems 19–20, see Sample Problem B.

19. What is the kinetic energy of an automobile with a mass of 1250 kg traveling at a speed of 11 m/s?

20. What speed would a fly with a mass of 0.55 g need in order to have the same kinetic energy as the automobile in item 19?

For problems 21–22, see Sample Problem C.

21. A 50.0 kg diver steps off a diving board and drops straight down into the water. The water provides an upward average net force of 1500 N. If the diver comes to rest 5.0 m below the water’s surface, what is the total distance between the diving board and the diver’s stopping point underwater?

22. In a circus performance, a monkey on a sled is given an initial speed of 4.0 m/s up a 25° incline. The combined mass of the monkey and the sled is 20.0 kg, and the coefficient of kinetic friction between the sled and the incline is 0.20. How far up the incline does the sled move?

For problems 23–25, see Sample Problem D.

23. A 55 kg skier is at the top of a slope, as shown in the illustration below. At the initial point A, the skier is 10.0 m vertically above the final point B.

a. Set the zero level for gravitational potential energy at B, and find the gravitational potential energy associated with the skier at A and at B. Then find the difference in potential energy between these two points.

b. Repeat this problem with the zero level at point A.

c. Repeat this problem with the zero level midway down the slope, at a height of 5.0 m.

24. A 2.00 kg ball is attached to a ceiling by a string. The distance from the ceiling to the center of the ball is 1.00 m, and the height of the room is 3.00 m. What is the gravitational potential energy associated with the ball relative to each of the following?

a. the ceiling

b. the floor

c. a point at the same elevation as the ball

25. A spring has a force constant of 500.0 N/m. Show that the potential energy stored in the spring is as follows:

a. 0.400 J when the spring is stretched 4.00 cm from equilibrium

b. 0.225 J when the spring is compressed 3.00 cm from equilibrium

c. zero when the spring is unstretched
CONSERVATION OF MECHANICAL ENERGY

Review Questions

26. Each of the following objects possesses energy. Which forms of energy are mechanical, which are nonmechanical, and which are a combination?
   a. glowing embers in a campfire
   b. a strong wind
   c. a swinging pendulum
   d. a person sitting on a mattress
   e. a rocket being launched into space

27. Discuss the energy transformations that occur during the pole-vault event shown in the photograph below. Disregard rotational motion and air resistance.

Practice Problems

For problems 33–34, see Sample Problem E.

33. A child and sled with a combined mass of 50.0 kg slide down a frictionless hill that is 7.34 m high. If the sled starts from rest, what is its speed at the bottom of the hill?

34. Tarzan swings on a 30.0 m long vine initially inclined at an angle of 37.0° with the vertical. What is his speed at the bottom of the swing if he does the following?
   a. starts from rest
   b. starts with an initial speed of 4.00 m/s

POWER

Practice Problems

For problems 35–36, see Sample Problem F.

35. If an automobile engine delivers 50.0 hp of power, how much time will it take for the engine to do 6.40 \times 10^5 J of work? (Hint: Note that one horsepower, 1 hp, is equal to 746 watts.)

36. Water flows over a section of Niagara Falls at the rate of 1.2 \times 10^6 kg/s and falls 50.0 m. How much power is generated by the falling water?
MIXED REVIEW

37. A 215 g particle is released from rest at point A inside a smooth hemispherical bowl of radius 30.0 cm, as shown at right. Calculate the following:
   a. the gravitational potential energy at A relative to B
   b. the particle’s kinetic energy at B
   c. the particle’s speed at B
   d. the potential energy and kinetic energy at C

38. A person doing a chin-up weighs 700.0 N, disregarding the weight of the arms. During the first 25.0 cm of the lift, each arm exerts an upward force of 355 N on the torso. If the upward movement starts from rest, what is the person’s speed at this point?

39. A 50.0 kg pole vaulter running at 10.0 m/s vaults over the bar. If the vaulter’s horizontal component of velocity over the bar is 1.0 m/s and air resistance is disregarded, how high was the jump?

40. An 80.0 N box of clothes is pulled 20.0 m up a 30.0° ramp by a force of 115 N that points along the ramp. If the coefficient of kinetic friction between the box and ramp is 0.22, calculate the change in the box’s kinetic energy.

41. Tarzan and Jane, whose total mass is 130.0 kg, start their swing on a 5.0 m long vine when the vine is at an angle of 30.0° with the horizontal. At the bottom of the arc, Jane, whose mass is 50.0 kg, releases the vine. What is the maximum height at which Tarzan can land on a branch after his swing continues? (Hint: Treat Tarzan’s and Jane’s energies as separate quantities.)

42. A 0.250 kg block on a vertical spring with a spring constant of $5.00 \times 10^3$ N/m is pushed downward, compressing the spring 0.100 m. When released, the block leaves the spring and travels upward vertically. How high does it rise above the point of release?

43. Three identical balls, all with the same initial speed, are thrown by a juggling clown on a tightrope. The first ball is thrown horizontally, the second is thrown at some angle above the horizontal, and the third is thrown at some angle below the horizontal. Disregarding air resistance, describe the motions of the three balls, and compare the speeds of the balls as they reach the ground.

44. A 0.60 kg rubber ball has a speed of 2.0 m/s at point A and kinetic energy of 7.5 J at point B. Determine the following:
   a. the ball’s kinetic energy at A
   b. the ball’s speed at B
   c. the total work done on the ball from A to B

45. Starting from rest, a 5.0 kg block slides 2.5 m down a rough 30.0° incline in 2.0 s. Determine the following:
   a. the work done by the force of gravity
   b. the mechanical energy lost due to friction
   c. the work done by the normal force between the block and the incline

46. A skier of mass 70.0 kg is pulled up a slope by a motor-driven cable. How much work is required to pull the skier 60.0 m up a 35° slope (assumed to be frictionless) at a constant speed of 2.0 m/s?

47. An acrobat on skis starts from rest 50.0 m above the ground on a frictionless track and flies off the track at a 45.0° angle above the horizontal and at a height of 10.0 m. Disregard air resistance.
   a. What is the skier’s speed when leaving the track?
   b. What is the maximum height attained?

48. Starting from rest, a 10.0 kg suitcase slides 3.00 m down a frictionless ramp inclined at 30.0° from the floor. The suitcase then slides an additional 5.00 m along the floor before coming to a stop. Determine the following:
   a. the suitcase’s speed at the bottom of the ramp
   b. the coefficient of kinetic friction between the suitcase and the floor
   c. the change in mechanical energy due to friction

49. A light horizontal spring has a spring constant of 105 N/m. A 2.00 kg block is pressed against one end of the spring, compressing the spring 0.100 m. After the block is released, the block moves 0.250 m to the right before coming to rest. What is the coefficient of kinetic friction between the horizontal surface and the block?
50. A 5.0 kg block is pushed 3.0 m at a constant velocity up a vertical wall by a constant force applied at an angle of 30.0° with the horizontal, as shown at right. If the coefficient of kinetic friction between the block and the wall is 0.30, determine the following:

a. the work done by the force on the block
b. the work done by gravity on the block
c. the magnitude of the normal force between the block and the wall

d. −16 J

51. A 25 kg child on a 2.0 m long swing is released from rest when the swing supports make an angle of 30.0° with the vertical.

a. What is the maximum potential energy associated with the child?
b. Disregarding friction, find the child’s speed at the lowest position.
c. What is the child’s total mechanical energy?
d. If the speed of the child at the lowest position is 2.00 m/s, what is the change in mechanical energy due to friction?

Graphing Calculator Practice

Visit go.hrw.com for answers to this Graphing Calculator activity.

Keyword HF6WRKXT

Work of Displacement

Work done, as you learned earlier in this chapter, is a result of the net applied force, the distance of the displacement, and the angle of the applied force relative to the direction of displacement. Work done is described by in the following equation:

\[ W_{\text{net}} = F_{\text{net}}d \cos \theta \]

The equation for work done can be represented on a graphing calculator as follows:

\[ Y_1 = FX \cos(\theta) \]

In this activity, you will use this equation and your graphing calculator to produce a table of results for various values of \( \theta \). Column one of the table will be the displacement (X) in meters, and column two will be the work done (\( Y_1 \)) in joules.

Visit go.hrw.com and enter the keyword HF6WRX to find this graphing calculator activity. Refer to Appendix B for instructions on downloading the program for this activity.
52. A ball of mass 522 g starts at rest and slides down a frictionless track, as shown at right. It leaves the track horizontally, striking the ground.
   a. At what height above the ground does the ball start to move?
   b. What is the speed of the ball when it leaves the track?
   c. What is the speed of the ball when it hits the ground?

Alternative Assessment

1. Design experiments for measuring your power output when doing push-ups, running up a flight of stairs, pushing a car, loading boxes onto a truck, throwing a baseball, or performing other energy-transferring activities. What data do you need to measure or calculate? Form groups to present and discuss your plans. If your teacher approves your plans, perform the experiments.

2. Investigate the amount of kinetic energy involved when your car’s speed is 60 km/h, 50 km/h, 40 km/h, 30 km/h, 20 km/h, and 10 km/h. (Hint: Find your car’s mass in the owner’s manual.) How much work does the brake system have to do to stop the car at each speed?
   If the owner’s manual includes a table of braking distances at different speeds, determine the force the braking system must exert. Organize your findings in charts and graphs to study the questions and to present your conclusions.

3. Investigate the energy transformations of your body as you swing on a swing set. Working with a partner, measure the height of the swing at the high and low points of your motion. What points involve a maximum gravitational potential energy? What points involve a maximum kinetic energy? For three other points in the path of the swing, calculate the gravitational potential energy, the kinetic energy, and the velocity. Organize your findings in bar graphs.

4. In order to save fuel, an airline executive recommended the following changes in the airlines’ largest jet flights:
   a. restrict the weight of personal luggage
   b. remove pillows, blankets, and magazines from the cabin
   c. lower flight altitudes by 5 percent
   d. reduce flying speeds by 5 percent
   Research the information necessary to calculate the approximate kinetic and potential energy of a large passenger aircraft. Which of the measures described above would result in significant savings? What might be their other consequences? Summarize your conclusions in a presentation or report.

5. Make a chart of the kinetic energies your body can have. Measure your mass and speed when walking, running, sprinting, riding a bicycle, and driving a car. Make a poster graphically comparing these findings.

6. You are trying to find a way to bring electricity to a remote village in order to run a water-purifying device. A donor is willing to provide battery chargers that connect to bicycles. Assuming the water-purification device requires 18.6 kW·h daily, how many bicycles would a village need if a person can average 100 W while riding a bicycle? Is this a useful way to help the village? Evaluate your findings for strengths and weaknesses. Summarize your comments and suggestions in a letter to the donor.

Alternative Assessment Answers

1. Student plans should be safe and should include measuring work and the time intervals.
2. Students should recognize that all of the car’s KE must be brought to zero, because \( v_f = 0 \text{ m/s} \). Therefore, the brake system must do as much work as the car’s KE (if air resistance and friction are neglected).
3. Student plans should be safe and should include measurements of height, mass, and speed. Kinetic energy is highest at the bottom of the swing.
4. Students will need to research information about altitude, friction, speed, and masses involved to evaluate the plans.
5. Student posters should indicate that increasing speed causes their KE to increase.
6. Students’ letters will vary but should acknowledge that 186 h of bicycling are needed for a day of use. Thus, at least eight bicycles would be required.
MULTIPLE CHOICE

1. In which of the following situations is work not being done?
   - A. A chair is lifted vertically with respect to the floor.
   - B. A bookcase is slid across carpeting.
   - C. A table is dropped onto the ground.
   - D. A stack of books is carried at waist level across a room.

2. Which of the following equations correctly describes the relation between power, work, and time?
   - F. \( W = \frac{P}{t} \)
   - G. \( W = \frac{t}{P} \)
   - H. \( P = \frac{W}{t} \)
   - J. \( P = \frac{t}{W} \)

Use the graph below to answer questions 3–5. The graph shows the energy of a 75 g yo-yo at different times as the yo-yo moves up and down on its string.

3. By what amount does the mechanical energy of the yo-yo change after 6.0 s?
   - A. 500 mJ
   - B. 0 mJ
   - C. −100 mJ
   - D. −600 mJ

4. What is the speed of the yo-yo after 4.5 s?
   - F. 3.1 m/s
   - G. 2.3 m/s
   - H. 3.6 m/s
   - J. 1.6 m/s

5. What is the maximum height of the yo-yo?
   - A. 0.27 m
   - B. 0.54 m
   - C. 0.75 m
   - D. 0.82 m

6. A car with mass \( m \) requires 5.0 kJ of work to move from rest to a final speed \( v \). If this same amount of work is performed during the same amount of time on a car with a mass of \( 2m \), what is the final speed of the second car?
   - F. \( 2v \)
   - G. \( \sqrt{2v} \)
   - H. \( \frac{v}{2} \)
   - J. \( \frac{v}{\sqrt{2}} \)

Use the passage below to answer questions 7–8.
A 70.0 kg base runner moving at a speed of 4.0 m/s begins his slide into second base. The coefficient of friction between his clothes and Earth is 0.70. His slide lowers his speed to zero just as he reaches the base.

7. How much mechanical energy is lost because of friction acting on the runner?
   - A. 1100 J
   - B. 560 J
   - C. 140 J
   - D. 0 J

8. How far does the runner slide?
   - F. 0.29 m
   - G. 0.57 m
   - H. 0.86 m
   - J. 1.2 m
Use the passage below to answer questions 9–10.

A spring scale has a spring with a force constant of 250 N/m and a weighing pan with a mass of 0.075 kg. During one weighing, the spring is stretched a distance of 12 cm from equilibrium. During a second weighing, the spring is stretched a distance of 18 cm.

9. How much greater is the elastic potential energy of the stretched spring during the second weighing than during the first weighing?

A. \( \frac{9}{4} \)
B. \( \frac{3}{2} \)
C. \( \frac{2}{3} \)
D. \( \frac{4}{9} \)

10. If the spring is suddenly released after each weighing, the weighing pan moves back and forth through the equilibrium position. What is the ratio of the pan’s maximum speed after the second weighing to the pan’s maximum speed after the first weighing? Consider the force of gravity on the pan to be negligible.

F. \( \frac{9}{4} \)
H. \( \frac{2}{3} \)
G. \( \frac{3}{2} \)
J. \( \frac{4}{9} \)

EXTENDED RESPONSE

Base your answers to questions 14–16 on the information below.

A projectile with a mass of 5.0 kg is shot horizontally from a height of 25.0 m above a flat desert surface. The projectile’s initial speed is 17 m/s. Calculate the following for the instant before the projectile hits the surface:

14. The work done on the projectile by gravity.
15. The change in kinetic energy since the projectile was fired.
16. The final kinetic energy of the projectile.
17. A skier starts from rest at the top of a hill that is inclined at 10.5° with the horizontal. The hillside is 200.0 m long, and the coefficient of friction between the snow and the skis is 0.075. At the bottom of the hill, the snow is level and the coefficient of friction is unchanged. How far does the skier move along the horizontal portion of the snow before coming to rest? Show all of your work.

SHORT RESPONSE

11. A student with a mass of 66.0 kg climbs a staircase in 44.0 s. If the distance between the base and the top of the staircase is 14.0 m, how much power will the student deliver by climbing the stairs?

Base your answers to questions 12–13 on the information below.

A 75.0 kg man jumps from a window that is 1.00 m above a sidewalk.

12. Write the equation for the man’s speed when he strikes the ground.

13. Calculate the man’s speed when he strikes the ground.

Test Tip When solving a mathematical problem, you must first decide which equation or equations you need to answer the question.
Chapter 5

Skills Practice Lab

Conservation of Mechanical Energy

A mass on a spring will oscillate vertically when it is lifted to the length of the relaxed spring and released. The gravitational potential energy increases from a minimum at the lowest point to a maximum at the highest point. The elastic potential energy in the spring increases from a minimum at the highest point, where the spring is relaxed, to a maximum at the lowest point, where the spring is stretched. Because the mass is temporarily at rest, the kinetic energy of the mass is zero at the highest and lowest points. Thus, the total mechanical energy at those points is the sum of the elastic potential energy and the gravitational potential energy.

A Hooke’s law apparatus combines a stand for mounting a hanging spring and a vertical ruler for measuring the displacement of a mass attached to the spring. In this lab, you will use a Hooke’s law apparatus to determine the spring constant of a spring. You will also collect data during the oscillation of a mass on the spring and use your data to calculate gravitational potential energy and elastic potential energy at different points in the oscillation.

OBJECTIVES

• Determine the spring constant of a spring.
• Calculate elastic potential energy.
• Calculate gravitational potential energy.
• Determine whether mechanical energy is conserved in an oscillating spring.

MATERIALS LIST

• Hooke’s law apparatus
• meterstick
• rubber bands
• set of masses
• support stand and clamp

SAFETY

• Tie back long hair, secure loose clothing, and remove loose jewelry to prevent their getting caught in moving or rotating parts. Put on goggles.
• Attach masses securely. Perform this experiment in a clear area. Swinging or dropped masses can cause serious injury.

PROCEDURE

Preparation

1. Read the entire lab procedure, and plan the steps you will take.

2. If you are not using a datasheet provided by your teacher, prepare a data table in your lab notebook with four columns and seven rows. In the first row, label the first through fourth columns Trial, Mass (kg), Stretched Spring (m), and Force (N). In the first column, label the second through seventh rows 1, 2, 3, 4, 5, and 6. Above or below the data table, make a space to enter the value for Initial Spring (m).

3. If you are not using a datasheet provided by your teacher, prepare a second data table in your lab notebook with three columns and seven rows. In the first row, label the first through third columns Trial, Highest Point

Lab Planning

Beginning on page T34 are preparation notes and teaching tips to assist you in planning.

Blank data tables (as well as some sample data) appear on the One-Stop Planner.

No Books in the Lab?

See the Datasheets for In-Text Labs workbook for a reproducible master copy of this experiment.

CBL™ Option

A CBL™ version of this lab appears in the CBL™ Experiments workbook.

Safety Caution

Remind students to attach masses securely and to make sure the area is clear before allowing masses to oscillate. Remind students not to pull too hard on the spring because it will not return to the correct equilibrium position. Also, do not add too much mass (which will stretch the spring to the point of deforming it).
work and energy

CHAPTER 5 LAB

Figure 1

Spring Constant

4. Set up the Hooke’s law apparatus as shown in Figure 1.

5. Place a rubber band around the scale at the initial resting position of the pointer, or adjust the scale or pan to read 0.0 cm. Record this position of the pointer as Initial Spring (m). If you have set the scale at 0.0 cm, record 0.00 m as the initial spring position.

6. Measure the distance from the floor to the rubber band on the scale. Record this measurement in the second data table under Initial Distance (m). This distance must remain constant throughout the lab.

7. Find a mass that will stretch the spring so that the pointer moves approximately one-quarter of the way down the scale.

8. Record the value of the mass. Also record the position of the pointer under Stretched Spring in the data table.

9. Perform several trials with increasing masses until the spring stretches to the bottom of the scale. Record the mass and the position of the pointer for each trial.

Conservation of Mechanical Energy

10. Find a mass that will stretch the spring to about twice its original length. Record the mass in the second data table. Leave the mass in place on the pan.

Tips and Tricks

- For best results, use weights of less than 1.0 N for steps 10–14.
- Show students how to read the scale on the Hooke’s law apparatus.
- Demonstrate releasing the mass hanger so it will oscillate vertically without twisting.
- Draw a diagram of the apparatus on the chalkboard, and label the distances students will be measuring in the lab: Initial Distance, Initial Spring, Stretched Spring, Highest Point, and Lowest Point. Show students how to refer to the diagram to find the elongation of the spring and the height of the mass at each point.

✓ Checkpoints

Step 5: Students should adjust the scale to zero at the initial position of the spring if possible.

Step 6: Make sure students are measuring the vertical distance from the floor to the initial position of the spring.

Step 13: Students may need to practice a technique to identify the highest and lowest points while the mass is oscillating. Without disturbing the apparatus, they might use pencils as pointers to mark the place until they can place their rubber bands.
11. Raise the pan until the pointer is at the zero position, the position where you measured the Initial Spring measurement.

12. Gently release the pan to let the pan drop. Watch closely to identify the high and low points of the oscillation.

13. Use a rubber band to mark the lowest position to which the pan falls, as indicated by the pointer. This point is the lowest point of the oscillation. Record the values as Highest Point and Lowest Point in your data table.

14. Perform several more trials, using a different mass for each trial. Record all data in your data table.

15. Clean up your work area. Put equipment away safely so that it is ready to be used again.

**ANALYSIS**

1. **Organizing Data** Use your data from the first data table to calculate the elongation of the spring. Use the equation elongation = initial spring − stretched spring.

2. **Organizing Data** For each trial, convert the masses used to measure the spring constant to their force equivalents. Use the equation $F_g = ma_g$.

3. **Organizing Data** For each trial, calculate the spring constant using the equation $k = \frac{force}{elongation}$. Take the average of all trials, and use this value as the spring constant.

4. **Organizing Data** Using your data from the second data table, calculate the elongation of the spring at the highest point of each trial. Use the equation elongation = highest point − initial spring. Refer to Figure 2.

5. **Organizing Data** Calculate the elongation of the spring at the lowest point of each trial. Use the equation elongation = lowest point − initial spring. Refer to Figure 2.

6. **Organizing Data** For each trial, calculate the elastic potential energy, $PE_{elastic} = \frac{1}{2}kx^2$, at the highest point of the oscillation.

7. **Organizing Data** For each trial, calculate the elastic potential energy at the lowest point of the oscillation.

8. **Analyzing Results** Based on your calculations in items 6 and 7, where is the elastic potential energy greatest? Where is it the least? Explain these results in terms of the energy stored in the spring.

9. **Organizing Data** Calculate the height of the mass at the highest point of each trial. Use the equation $\text{highest} = \text{initial distance} − \text{elongation}$.
10. **Organizing Data** Calculate the height of the mass at the lowest point of each trial. Use the equation $\text{lowest} = \text{initial distance} - \text{elongation}$.

11. **Organizing Data** For each trial, calculate the gravitational potential energy, $PE_g = ma_g h$, at the highest point of the oscillation.

12. **Organizing Data** For each trial, calculate the gravitational potential energy at the lowest point of the oscillation.

13. **Analyzing Results** According to your calculations in items 11 and 12, where is the gravitational potential energy the greatest? Where is it the least? Explain these results in terms of gravity and the height of the mass and the spring.

14. **Organizing Data** Find the total potential energy at the top of the oscillation and at the bottom of the oscillation.

**CONCLUSIONS**

15. **Drawing Conclusions** Based on your data, is mechanical energy conserved in the oscillating mass on the spring? Explain how your data support your answers.

16. **Making Predictions** How would using a stiffer spring affect the value for the spring constant? How would this change affect the values for the elastic and gravitational potential energies?

**EXTENSIONS**

17. **Extending Ideas** Use your data to find the midpoint of the oscillation for each trial. Calculate the gravitational potential energy and the elastic potential energy at the midpoint. Use the principle of the conservation of mechanical energy to find the kinetic energy and the speed of the mass at the midpoint.

18. **Designing Experiments** Based on what you have learned in this lab, design an experiment to measure the spring constants of springs and other elastic materials in common products, such as the springs inside ball point pens, rubber bands, or even elastic waistbands. Include in your plan a way to determine how well each spring or elastic material conserves mechanical energy. If you have time and your teacher approves your plan, carry out the experiment on several items, and make a table comparing your results for the various items.
### Chapter Review, Assessment, and Standardized Test Preparation

#### Objectives

**PACING: 45 min**  
pp. 196–197

**Chapter Opener**

**PACING: 45 min**  
pp. 198–204

**Section 1 Momentum and Impulse**
- Compare the momentum of different moving objects.
- Compare the momentum of the same object moving with different velocities.
- Identify examples of change in the momentum of an object.
- Describe changes in momentum in terms of force and time.

**PACING: 90 min**  
pp. 205–211

**Section 2 Conservation of Momentum**
- Describe the interaction between two objects in terms of the change in momentum of each object.
- Compare the total momentum of two objects before and after they interact.
- State the law of conservation of momentum.
- Predict the final velocities of objects after collisions, given the initial velocities.

**PACING: 45 min**  
pp. 212–220

**Section 3 Elastic and Inelastic Conditions**
- Identify different types of collisions.
- Determine the changes in kinetic energy during perfectly inelastic collisions.
- Compare conservation of momentum and conservation of kinetic energy in perfectly inelastic and elastic collisions.
- Find the final velocity of an object in perfectly inelastic and elastic collisions.

**PACING: 90 min**

#### Labs, Demonstrations, and Activities

<table>
<thead>
<tr>
<th>Objective</th>
<th>Lab</th>
<th>Activity</th>
<th>Technology Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compare the momentum of different moving objects.</td>
<td>TE Demonstration Impulse, p.200</td>
<td>OSP Lesson Plans</td>
<td></td>
</tr>
<tr>
<td>Compare the momentum of the same object moving with different velocities.</td>
<td>ANC CBL® Experiment Impulse and Momentum*</td>
<td>OSP Interactive Tutor Module 7, Conservation of Momentum</td>
<td></td>
</tr>
<tr>
<td>Identify examples of change in the momentum of an object.</td>
<td>SE Inquiry Lab Conservation of Momentum, pp. 230–231</td>
<td>OSP Interactive Tutor Module 7, Worksheet</td>
<td></td>
</tr>
<tr>
<td>Describe changes in momentum in terms of force and time.</td>
<td>ANC Datasheet Inquiry Lab, Conservation of Momentum*</td>
<td>OSP Interactive Tutor Module 7, Conservation of Momentum</td>
<td></td>
</tr>
<tr>
<td>Describe the interaction between two objects in terms of the change in momentum of each object.</td>
<td>ANC Datasheet Skills Practice Lab, Conservation of Momentum*</td>
<td>OSP Interactive Tutor Module 7, Conservation of Momentum</td>
<td></td>
</tr>
<tr>
<td>Compare the total momentum of two objects before and after they interact.</td>
<td>ANC CBL® Experiment Conservation of Momentum*</td>
<td>OSP Interactive Tutor Module 7, Conservation of Momentum</td>
<td></td>
</tr>
<tr>
<td>State the law of conservation of momentum.</td>
<td>SE Quick Lab Elastic and Inelastic Collisions, p. 217</td>
<td>OSP Lesson Plans</td>
<td></td>
</tr>
<tr>
<td>Predict the final velocities of objects after collisions, given the initial velocities.</td>
<td>TE Demonstration Inelastic Collisions, p.212</td>
<td>OSP Lesson Plans</td>
<td></td>
</tr>
</tbody>
</table>

#### Technology Resources

- **CD Visual Concepts, Chapter 6**
- **OSP Lesson Plans**
  - TR 20 Impulse-Momentum Theorem
  - TR 21A Stopping Distances
- **OSP Interactive Tutor**
  - Module 7, Conservation of Momentum
  - Module 7, Worksheet
- **ANC Study Guide Worksheet Mixed Review**
- **ANC Chapter Test A**
- **ANC Chapter Test B**
- **OSP Test Generator**

### Online and Technology Resources

**Visit go.hrw.com to access online resources. Click Holt Online Learning for an online edition of this textbook, or enter the keyword HF6 Home for other resources. To access this chapter’s extensions, enter the keyword HF6MOMXT.**

**One-Step Planner® CD-ROM**

- ExamView® Test Generator
- Interactive Teacher Edition
- Holt PuzzlePro®
- Holt PowerPoint® Resources

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**Chapter: Momentum and Collisions**
### SKILLS DEVELOPMENT RESOURCES

| SE | Sample Set A | Momentum, pg. 199 | **BASIC** |
| SE | Sample Set B | Force and Impulse, pg. 201 | **BASIC** |
| TE | Classroom Practice | p. 201 | **BASIC** |
| ANC | Problem Workbook* and OSP Problem Bank | Sample Set A | **BASIC** |
| ANC | Problem Workbook* and OSP Problem Bank | Sample Set B | **BASIC** |
| SE | Sample Set C | Stopping Distance, pp. 202–203 | **BASIC** |
| TE | Classroom Practice | p. 202 | **BASIC** |
| ANC | Problem Workbook* and OSP Problem Bank | Sample Set C | **BASIC** |

| SE | Sample Set D | Conservation of Momentum, pp. 208–209 | **GENERAL** |
| TE | Classroom Practice | p. 206 | **GENERAL** |
| ANC | Problem Workbook* and OSP Problem Bank | Sample Set D | **GENERAL** |
| SE | Conceptual Challenge | p. 206 | **GENERAL** |

| SE | Sample Set E | Perfectly Inelastic Collisions, pp. 213–214 | **GENERAL** |
| TE | Classroom Practice | p. 213 | **GENERAL** |
| ANC | Problem Workbook* and OSP Problem Bank | Sample Set E | **GENERAL** |
| SE | Sample Set F | Kinetic Energy in Perfectly Inelastic Collisions, pp. 215–216 | **GENERAL** |
| TE | Classroom Practice | p. 215 | **GENERAL** |
| ANC | Problem Workbook* and OSP Problem Bank | Sample Set F | **GENERAL** |
| SE | Sample Set G | Elastic Collisions, pp. 218–219 | **ADVANCED** |
| TE | Classroom Practice | p. 218 | **ADVANCED** |
| ANC | Problem Workbook* and OSP Problem Bank | Sample Set G | **ADVANCED** |

### REVIEW AND ASSESSMENT

| SE | Section Review | p. 204 | **GENERAL** |
| ANC | Study Guide Worksheet | Section 1* | **GENERAL** |
| ANC | Quiz Section 1* | **BASIC** |

| SE | Section Review | p. 211 | **GENERAL** |
| ANC | Study Guide Worksheet | Section 2* | **GENERAL** |
| ANC | Quiz Section 2* | **BASIC** |

| SE | Section Review | p. 220 | **ADVANCED** |
| ANC | Study Guide Worksheet | Section 3* | **ADVANCED** |
| ANC | Quiz Section 3* | **GENERAL** |

### CORRELATIONS

- National Science Education Standards
- UCP 1,2,3
- HNS 3
- UCP 1,2,3,5
- SAI 1,2
- ST 1,2
- SPSP 1,4,5
- PS 5a
- UCP 1,2,3
- SAI 1,2
- PS 5a

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**CNN Science in the News**

Each video segment is accompanied by a Critical Thinking Worksheet.

**Segment 6**

Egg Drop Contest
Section 1 defines momentum in terms of mass and velocity, introduces the concept of impulse, and relates impulse and momentum.

Section 2 explores the law of conservation of momentum and uses this law to predict the final velocity of an object after a collision.

Section 3 distinguishes between elastic, perfectly inelastic, and inelastic collisions and discusses whether kinetic energy is conserved in each type of collision.

About the Illustration
Soccer is a good example to help students understand the concept of momentum and distinguish it from force, velocity, and kinetic energy. This photograph is a dramatic example of a player colliding with a ball and changing the momentum of the ball. Use this example to illustrate the vector nature of momentum; the photograph can open a discussion about how the direction as well as the magnitude of momentum is affected by the collision.

Interactive Problem-Solving Tutor
See Module 7
“Conservation of Momentum” promotes additional development of problem-solving skills for this chapter.