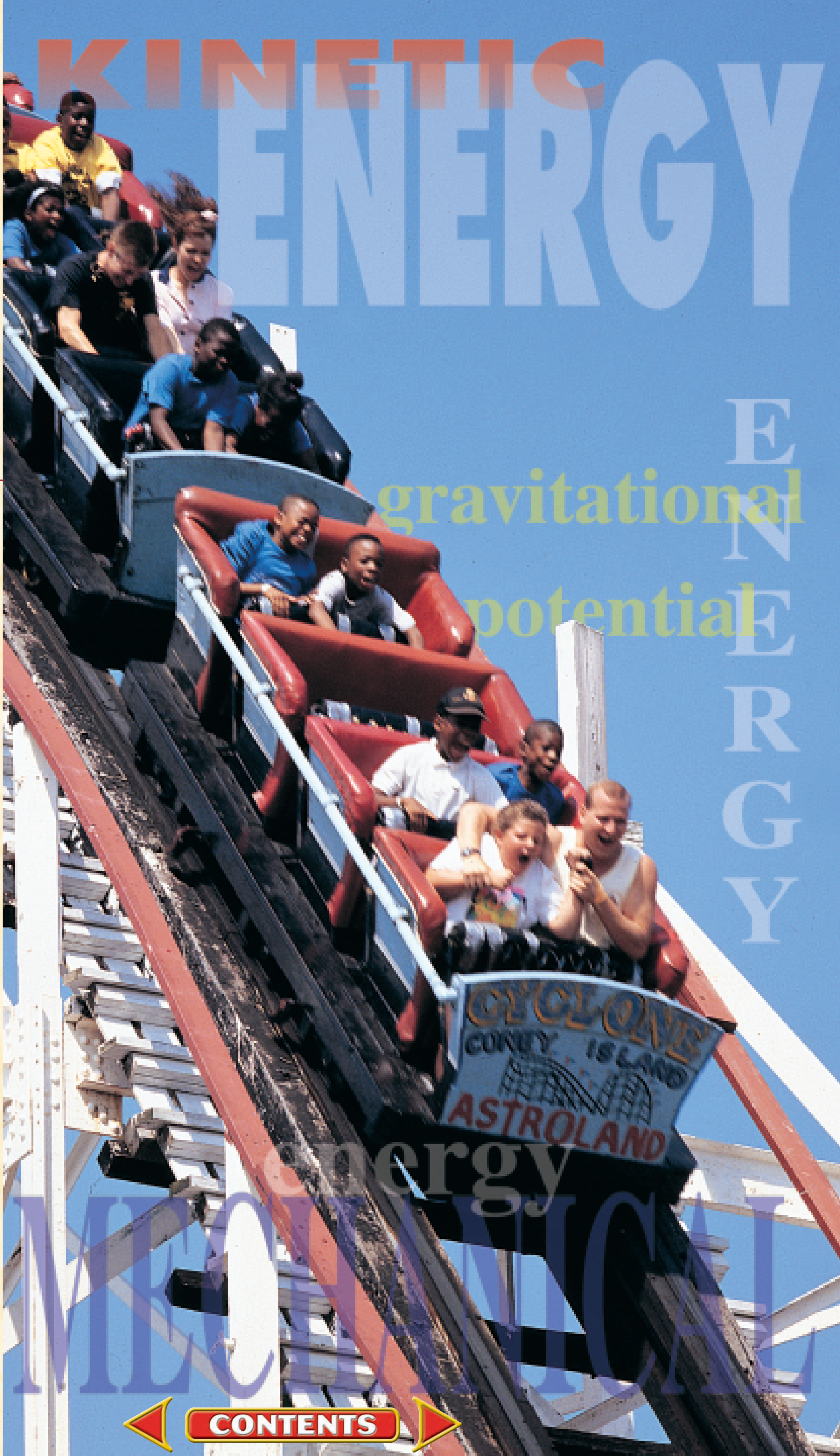
Whoosh!

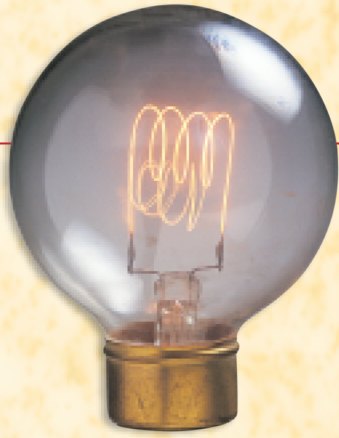
The roller coaster slowly climbs the first hill. Then, hang onto your hat! Down, down, down it flies until it reaches the bottom and begins to climb the next hill. Must the first hill of a roller coaster be the highest one?

Look at the text on page 259 for the answer.



CHAPTER

11 Energy



In everyday speech, the word *energy* is used many different ways. A child who runs and plays long after adults are tired is said to be full of energy. Certain fruit-and-cereal bars are advertised as energy bars. The sun provides solar energy for the planet. Companies that supply your home with electricity, natural gas, or heating fuel and your car with gasoline are called energy companies. When these resources become scarce and more expensive, the media report stories of an energy crisis.

Physicists use the term *energy* in a much more precise way. You began your study of energy in the last chapter. You learned that a change in the energy of a system is called work. That is, work transfers energy between an environment and a system. You also found that humans have devised several types of machines in order to produce more work with less effort. Now you will build on that knowledge.

In this chapter, you'll investigate a variety of forms of energy that objects can have. You'll learn about ways in which energy is transferred from one form to another and about methods of keeping track of all those changes. You'll be able to describe the difference between the water at the top of a waterfall and the water at the bottom of the waterfall. You'll understand why the nail you hammer into the wall becomes warm. You'll also be able to determine whether or not the first hill of a roller coaster must always be the highest one.

WHAT YOU'LL LEARN

- You will learn that energy is simply the ability to do something.
- You will learn that the total amount of energy in a closed system never changes; energy just changes form.

WHY IT'S IMPORTANT

- How energy changes form, and how much energy remains in a useful form, can influence how much you accomplish in an hour, in a day, and in your lifetime.

PHYSICS Online

To find out more about energy, visit the Glencoe Science Web site at **science.glencoe.com**

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CONTENTS

11.1 The Many Forms of Energy

OBJECTIVES

- **Use a model** to relate work and energy.
- **Calculate** the kinetic energy of a moving object.
- **Determine** how to find the gravitational potential energy of a system.
- **Identify** ways in which elastic potential energy is stored in a system.

In Chapter 10, you were introduced to the work-energy theorem. You learned that when work is done on a system, the energy of that system increases. On the other hand, if the system does work, then the energy of the system decreases. Those are pretty abstract ideas. Let's make them more like real life and develop a graphic model to give you a picture of what is going on.

A Model of the Work-Energy Theorem

If you have a job, the amount of money you have increases every time you are paid. This process can be represented with a bar graph, as shown in **Figure 11–1a.** The bar representing the money you have before you are paid is shorter than the bar representing the amount you have after you are paid. The difference in height of the two bars, the cash flow, is equal to your pay.

Now, what happens when you spend money? The total amount of money you have decreases. As shown in **Figure 11–1b,** the bar that represents the amount of money you had before you bought that new CD is higher than the bar that stands for the amount remaining after your shopping trip. The difference is the cost of the CD. Cash flow is shown as a bar below the axis, representing a negative number.

Throwing a ball But what does this have to do with work and energy? In Chapter 10, you read that when you exert a constant force, ***F,*** on an object through a distance, ***d,*** in the direction of the force, you do an amount of work, represented by $W = Fd$, on that object. The work is positive, and the energy of the object increases by an amount equal to W. Suppose the object is a ball, and you exert a force to throw the ball. As a result of the force you apply, the ball gains an energy of motion that

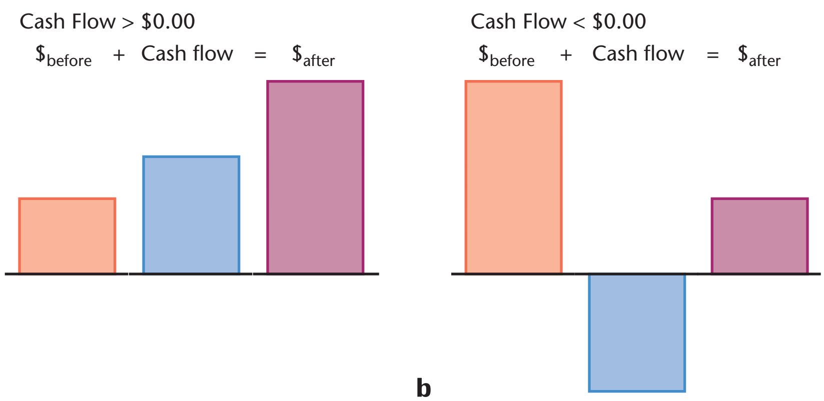


FIGURE 11–1 When you earn money, the amount of cash increases **(a).** When you spend money, the amount of cash decreases **(b).**

CONTENTS

is referred to as kinetic energy. This process is shown in **Figure 11–2a.** You can again use a bar graph to represent the process. This time, the height of the bar represents an amount of work, or energy, measured in joules. The kinetic energy after the work is done is equal to the sum of the initial kinetic energy plus the work done on the ball.

Catching a ball What happens when you catch a ball? Before hitting your hands or glove, the ball is moving, so it has kinetic energy. In catching it, you exert a force on the ball in the direction opposite to its motion. Therefore, you do negative work on it, causing it to stop. Now that the ball isn't moving, it has no kinetic energy. This process and the bar graph that represents it are shown in **Figure 11–2b.** The initial kinetic energy of the ball is positive: kinetic energy is always positive. The work done on the ball is negative, so the bar graph representing the work is below the axis. The final kinetic energy is zero because the ball has stopped. Again, kinetic energy after the ball has stopped is equal to the sum of the initial kinetic energy plus the work done on the ball.

Kinetic Energy

As you learned in Chapter 10, the kinetic energy of an object is represented by the equation $K = 1/2mv^2$, where m is the mass of the object and v is its velocity. The kinetic energy is proportional to the object's mass. Thus, a 7.26-kg shot thrown through the air has much more kinetic energy than a 148-g baseball with the same velocity. The kinetic energy of an object is also proportional to the square of the velocity of the object. A car speeding at 30 m/s has four times the kinetic energy of the same car moving at 15 m/s. Kinetic energy, like work, is measured in joules. **Table 11–1** on the next page shows the kinetic energies of some typical moving objects.

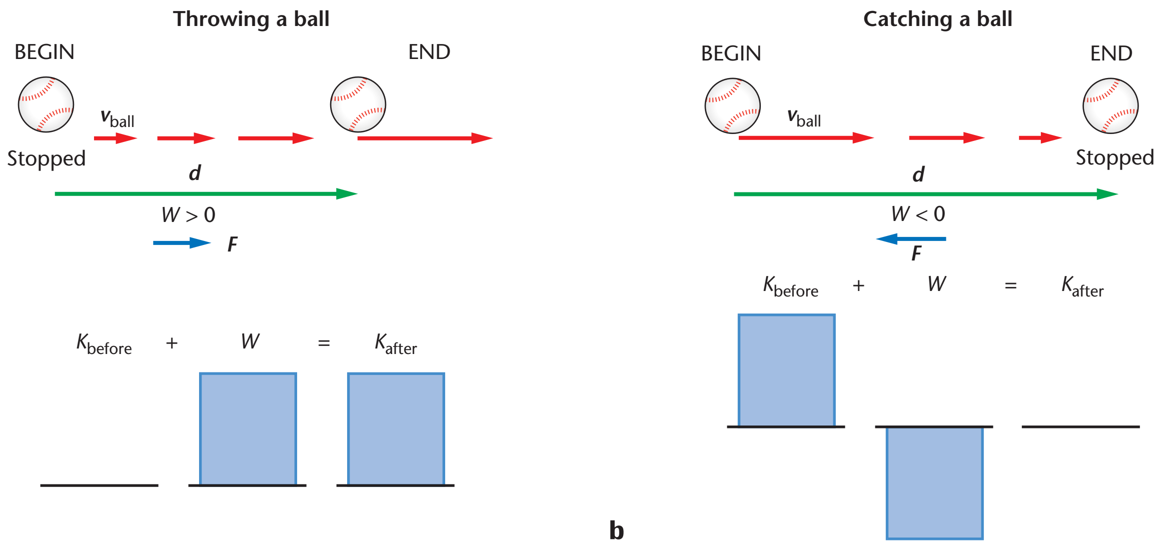
Pocket Lab

Energy in Coins

Does your car require more or less stopping distance when it is loaded with passengers than when you are driving alone? A short activity will help you to answer this question. Lay a ruler on a smooth table. Place two quarters against the edge of the ruler. Momentarily push the two quarters at the same speed across the table, and then stop the ruler. The two quarters should slide the same distance before stopping. Now tape another coin on top of one quarter to increase its mass. Again push the coins with the ruler.

Analyze and Conclude Does the stopping distance depend upon the mass? Explain.

FIGURE 11–2 When you throw a ball, you do work on it. The ball gains kinetic energy as a result **(a).** When you catch a ball, it stops because you exert a force on it in the opposite direction from its motion **(b).**



a **b**

TABLE 11–1		
Typical Kinetic Energy		
Object	**Mass**	**Kinetic Energy (J)**
Aircraft carrier	91 400 tons at 30 knots	9.9×10^{9}
Orbiting satellite	100 kg at 7.8 km/s	3.0×10^{9}
Trailer truck	5700 kg at 100 km/h	2.2×10^{6}
Compact car	750 kg at 100 km/h	2.9×10^{5}
Football linebacker	110 kg at 9.0 m/s	4.5×10^{3}
Pitched baseball	148 g at 45 m/s	1.5×10^{2}
Falling nickel	5 g from 50-m height	2.5
Bumblebee	2 g at 2 m/s	4×10^{-3}
Snail	5 g at 0.05 km/h	4.5×10^{-7}

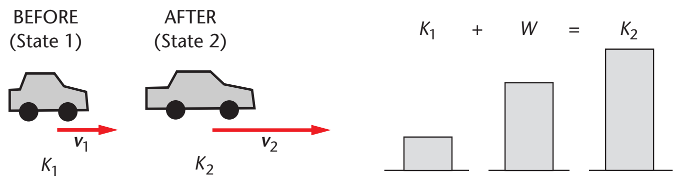
Example Problem

Kinetic Energy and Work

An 875-kg compact car speeds up from 22.0 to 44.0 m/s while passing another car. What were its initial and final energies, and how much work was done on the car to increase its speed?

Sketch the Problem

- Sketch the initial and final conditions.
- Make a bar graph.



Calculate Your Answer

Known:	**Unknown:**
$m = 875$ kg	$K_1 = ?$
$v_1 = 22.0$ m/s	$K_2 = ?$
$v_2 = 44.0$ m/s	$W = ?$

Strategy:

Use the initial and final speeds of the car to calculate kinetic energy.

The work done equals the change in kinetic energy.

Calculations:

$K = 1/2\, mv^2$

$K_1 = 1/2(875\text{ kg})(22.0\text{ m/s})^2 = 2.12 \times 10^5\text{ J}$

$K_2 = 1/2(875\text{ kg})(44.0\text{ m/s})^2 = 8.47 \times 10^5\text{ J}$

$W = K_2 - K_1 = (8.47 - 2.12) \times 10^5\text{ J}$
$= 6.35 \times 10^5\text{ J}$

Check Your Answer

- Do the signs make sense? K should be positive. $W > 0$ as K increases.
- Are the units correct? The answer should be in J, which equals $\text{kg}\cdot\text{m}^2/\text{s}^2$.
- Is the magnitude realistic? It should be similar to the listing in **Table 11–1** for a compact car.

Practice Problems

1. Consider the compact car in the Example Problem.
   a. Write 22.0 m/s and 44.0 m/s in km/h.
   b. How much work is done in slowing the car to 22.0 m/s?
   c. How much work is done in bringing it to rest?
   d. Assume that the force that does the work slowing the car is constant. Find the ratio of the distance needed to slow the car from 44.0 m/s to 22.0 m/s to the distance needed to slow it from 22.0 m/s to rest.
2. A rifle can shoot a 4.20-g bullet at a speed of 965 m/s.
   a. Draw work-energy bar graphs and free-body diagrams for all parts of this problem.
   b. Find the kinetic energy of the bullet as it leaves the rifle.
   c. What work is done on the bullet if it starts from rest?
   d. If the work is done over a distance of 0.75 m, what is the average force on the bullet?
   e. If the bullet comes to rest by penetrating 1.5 cm into metal, what is the magnitude and direction of the force the metal exerts? Again, assume that the force is constant.
3. A comet with a mass of 7.85×10^{11} kg strikes Earth at a speed of 25.0 km/s.
   a. Find the kinetic energy of the comet in joules.
   b. Compare the work that is done by Earth in stopping the comet to the 4.2×10^{15} J of energy that were released by the largest nuclear weapon ever built. Such a comet collision has been suggested as having caused the extinction of the dinosaurs.
4. **Table 11–1** shows that 2.2×10^6 J of work are needed to accelerate a 5700-kg trailer truck to 1.0×10^2 km/h.
   a. What would be the truck's speed if half as much work were done on it?
   b. What would be the truck's speed if twice as much work were done on it?

Stored Energy

Imagine a group of boulders high on a hill. Objects such as these boulders that have been lifted up against the force of gravity have stored, or potential, energy. Now imagine a rock slide in which the boulders are shaken loose. They fall, picking up speed as their potential energy is converted to kinetic energy. In the same way, a small spring-loaded toy such as the one pictured in **Figure 11–3** has energy stored in a compressed spring. While both of these examples represent energy stored by mechanical means, there are many other means of storing energy. Automobiles, for example, carry their energy stored in the form

F.Y.I.

The matter in one pound of anything, when it is completely converted into energy according to $E = mc^2$, will produce 4.086×10^{16} J (11 400 000 000 kWh) of energy.

FIGURE 11–3 This spring-loaded jack-in-the-box had energy stored in its compressed spring. When the spring was released, the energy was converted to kinetic energy.

F.Y.I.

The gravitational potential energy stored in a block of stone when it was lifted to the top of a pyramid 2500 years ago is still there undiminished. Making allowances for erosion, if the stone were dropped today, it would do as much work as when it was first put into place.

of chemical energy in the gasoline tank. The conversion of energy from one form to another is the focus of many nations' industries and is an integral part of modern life.

How does the money model that was discussed earlier illustrate the transformation of energy from one form to another? Money, too, can come in different forms. You can think of money in the bank as stored money, or potential spending money. Depositing money in your bank account or getting it out with an ATM card doesn't change the total amount of money you have; it just converts it from one form to another. The height of the bar graph in **Figure 11–4** represents the amount of money in each form. In the same way, you can use a bar graph to represent the amount of energy in various forms that a system has.

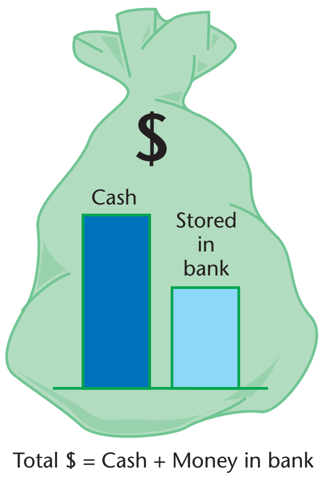


FIGURE 11–4 Money in the bank and cash in your pocket are different forms of the same thing.

Gravitational Potential Energy

Look at the balls being juggled in **Figure 11–5.** If you consider the system to be only one ball, then it has several external forces exerted on it. The force of the juggler's hand does work, giving the ball its original kinetic energy. After the ball leaves his hand, only the force of gravity acts on it. How much work does gravity do on the ball as its height changes?

Let h represent the ball's height measured from the juggler's hand. On the way up, its displacement is up, but the force on the ball, $\boldsymbol{F}_g$, is downward, so the work done by gravity, $W_{\text{by gravity on ball}} = -mgh$, is negative. On the way back down, the force and displacement are in the same direction, so the work done by gravity, $W_{\text{by gravity on ball}} = mgh$, is positive. The magnitude of the work is the same; only the sign changes. Thus, while the ball is moving upward, gravity does negative work, slowing the ball to a stop. On the way back down, gravity does positive work, increasing the ball's speed and thereby increasing its kinetic energy. The ball recovers all of the kinetic energy it originally had when it returns to the height at which it left the juggler's hand. It is as if the ball's kinetic energy is stored in another form as the ball rises and is returned to kinetic energy as the ball falls. The notion that energy may take different forms will be discussed in more detail in a later section.

If you choose a system to consist of an object plus Earth, then the gravitational attraction between the object and Earth is an interaction force between members of the system. If the object moves away from Earth, energy is stored in the system as a result of the gravitational interaction between the object and Earth. This stored energy is called the **gravitational potential energy** and is represented by the symbol U_g. In the example of the juggler, where gravity was an external force, the change in the potential energy of the object is then the negative of the work done. Thus, the gravitational potential energy is represented by

Gravitational Potential Energy $\quad U_g = mgh,$

where m is the mass of the object, g is the acceleration resulting from gravity, and h is the distance the object has risen above the position it had when U_g was defined to be zero. **Figure 11–6** shows the energy of a system consisting of one of the juggler's balls plus Earth. The energy in the system exists in two forms: kinetic energy and gravitational potential energy. At the beginning of the ball's flight, the energy is all in the form of kinetic energy. On the way up, as the ball slows, energy is changed from kinetic to potential. At the top of the ball's flight, when the ball instantaneously comes to rest, the energy is all potential. On the way back down, potential energy is changed back into kinetic energy. The sum of kinetic and potential energy is constant because no work is done on the system by any force external to the system.

FIGURE 11–5 Kinetic and potential energy are constantly being exchanged when juggling.

Choosing a reference level In the example of juggling a ball, height was measured from the place at which the ball left the juggler's hand. At that height, $h = 0$, the gravitational potential energy was defined to be zero. This choice of a **reference level,** at which the potential energy is defined to be zero, is arbitrary; the reference level may be taken as any position that is convenient for solving a given problem.

If the highest point the ball reached had been chosen as zero, as illustrated in **Figure 11–6b,** then the potential energy of the system would have been zero there and negative at the beginning and end of the flight. Although the total energy in the system would have been different, it would not have changed at any point during the flight. Only *changes* in energy, both kinetic and potential, can be measured. Because the initial energy of a real physical system is not known, the total energy of the system cannot be determined.

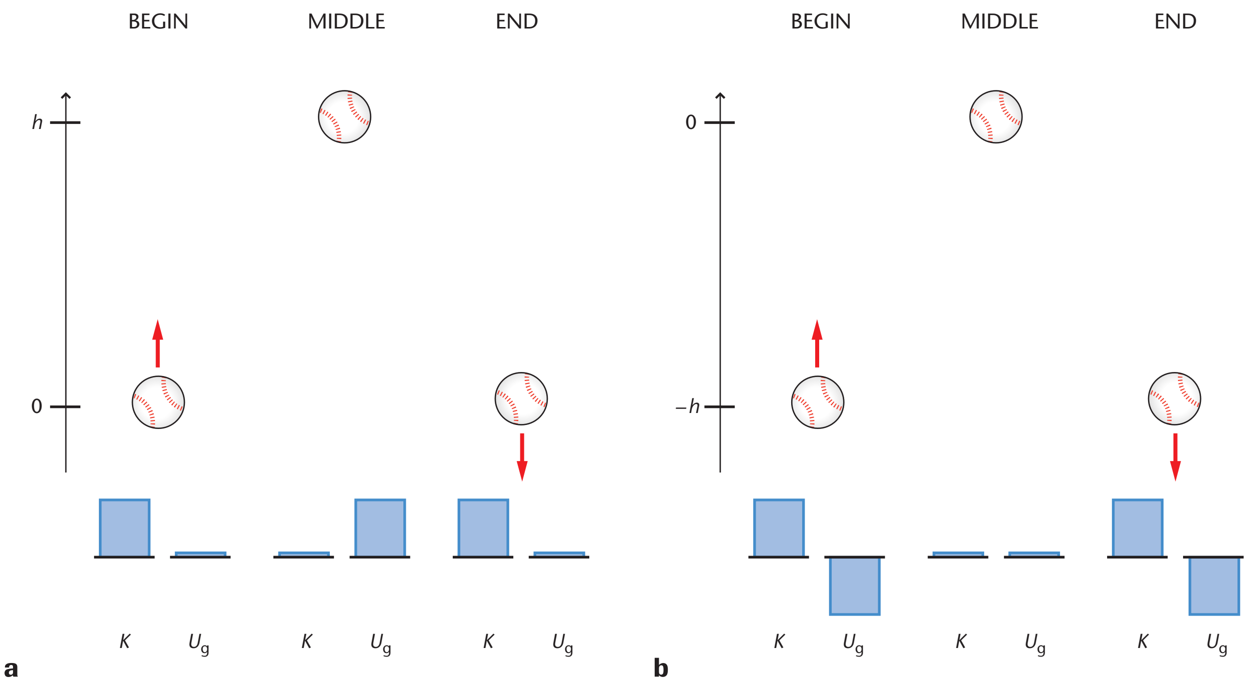


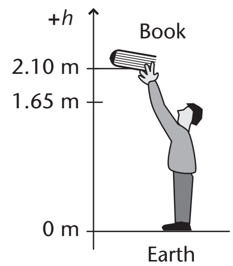
FIGURE 11–6 The energy of a ball is converted from one form to another in various stages of its flight **(a).** Note that the choice of a reference level is arbitrary but that the total energy remains constant **(b).**

Example Problem

Gravitational Potential Energy

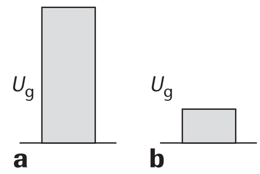
You lift a 2.00-kg textbook from the floor to a shelf 2.10 m above the floor.

a. What is the book's gravitational potential energy relative to the floor?
b. What is its gravitational potential energy relative to your head, assuming that you're 1.65 m tall?



Sketch the Problem

- Sketch the initial and final conditions.
- Choose a reference level.
- Make a bar graph.



Calculate Your Answer

Known:

$m = 2.00$ kg

$h_{shelf} = 2.10$ m

$h_{head} = 1.65$ m

$g = 9.80\ \text{m/s}^2$

Unknown:

U_g (relative to floor) = ?

U_g (relative to head) = ?

Strategy:
In both **a** and **b,** the reference level is below the book, so the gravitational potential energy of the system is positive.

Calculations:

$U_g = mgh$

a. $h = 2.10\ \text{m} - 0.00\ \text{m} = 2.10\ \text{m}$

$U_g = (2.00\ \text{kg})(9.80\ \text{m/s}^2)(2.10\ \text{m}) = 41.2\ \text{J}$

b. $h = 2.10\ \text{m} - 1.65\ \text{m} = 0.45\ \text{m}$

$U_g = (2.00\ \text{kg})(9.80\ \text{m/s}^2)(0.45\ \text{m}) = 8.82\ \text{J}$

Check Your Answer

- Are the units correct? Energy is in $\text{kg}\cdot\text{m}^2/\text{s}^2 = \text{J}$.
- Do the signs make sense? Both are positive because the book is above the reference level.
- Is the magnitude realistic? The energy relative to your head is less than 1/4 of the energy relative to the floor, which is similar to the ratio of the distances.

Practice Problems

5. For the preceding Example Problem, select the shelf as the reference level. The system is the book plus Earth.
  a. What is the gravitational potential energy of the book at the top of your head?
  b. What is the gravitational potential energy of the book at the floor?

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6. A 90-kg rock climber first climbs 45 m up to the top of a quarry, then descends 85 m from the top to the bottom of the quarry. If the initial height is the reference level, find the potential energy of the system (the climber plus Earth) at the top and the bottom. Draw bar graphs for both situations.
7. A 50.0-kg shell is shot from a cannon at Earth's surface to a height of 425 m. The system is the shell plus Earth, and the reference level is Earth's surface.
   a. What is the gravitational potential energy of the system when the shell is at this height?
   b. What is the change in the potential energy when the shell falls to a height of 225 m?
8. A 7.26-kg bowling ball hangs from the end of a 2.5-m rope. The ball is pulled back until the rope makes a 45° angle with the vertical.
   a. What is the gravitational potential energy of the system?
   b. What system and what reference level did you use in your calculation?

HELP WANTED

LOCK-AND-DAM CONSTRUCTION ENGINEERS

Wanted: civil, mechanical, and geotechnical engineers to design a new dam and supervise its construction. Will work with geologists to analyze the underlying soil and rock for seepage or earthquake activity, and with biologists to consider the environmental impact of the dam. College degree in engineering required. For more information, contact:
U.S. Army Corps of Engineers
Environmental Division
Directorate of Military Programs
441 G Street
Washington, DC 20314-1000

Elastic Potential Energy

When the string on the bow shown in **Figure 11–7** is pulled, work is done on the bow, storing energy in it. If you choose the system to be the bow, the arrow, and Earth, then you increase the energy of the system. When the string and arrow are released, energy is changed into kinetic energy. The energy stored in the pulled string is called **elastic potential energy.** Elastic potential energy is often stored in rubber balls, rubber bands, slingshots, and trampolines.

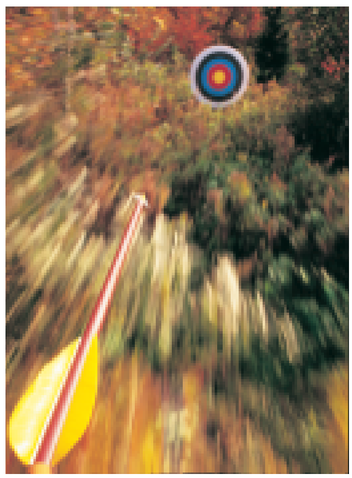


FIGURE 11–7 Elastic potential energy is stored in the string of this bow. Before the string is released, the energy is all potential. As the string is released, the energy is transferred to the arrow as kinetic energy.

Energy can also be stored in the bending of an object. When stiff metal or bamboo poles were used in pole-vaulting, the poles did not bend easily. Little work was done on the poles and consequently, the poles did not store much potential energy. Since the flexible fiberglass pole was introduced, record heights have soared. The pole-vaulter runs with the flexible pole, then plants its end into a socket in the ground. Work is done to bend the pole as the kinetic energy of the runner is converted to elastic potential energy. Then, as the pole straightens, the elastic potential energy is converted to gravitational potential energy and kinetic energy as the vaulter is lifted as high as 6 m above the ground. The increased capacity for the pole to store energy is reflected in additional height.

11.1 Section Review

1. In each of the following situations, the system consists of a ball and Earth. Draw bar graphs that describe the work done and changes in energy forms.
   a. You throw a ball horizontally.
   b. The horizontally thrown ball is caught in a mitt.
   c. You throw a ball vertically, and it comes to rest at the top of its flight.
   d. The ball falls back to Earth, where you catch it.
2. You use a toy dart gun to shoot the dart straight up. The system is the gun, the dart, and Earth. Draw bar graphs that describe the energy forms when
   a. you have pushed the dart into the gun barrel, thus compressing the spring.
   b. the spring expands and the dart leaves the gun barrel after you pull the trigger.
   c. the dart reaches the top of its flight.
3. You use an air hose to exert a constant horizontal force on a puck on a frictionless air table. You keep the hose aimed at the puck so that the force on it is constant as the puck moves a fixed distance.
   a. Explain what happens in terms of work and energy. Draw bar graphs as part of your explanation.
   b. You now repeat the experiment. Everything is the same except that the puck has half the mass. What will be the same? What will be different? In what way?
4. **Critical Thinking** You now modify the experiment slightly by applying the constant force for a fixed amount of time.
   a. Explain what happens in terms of impulse and momentum.
   b. What happens now when the mass of the puck is reduced?
   c. Compare the kinetic energies of the two pucks.

Down the Ramp

Problem

What factors affect the speed of a cart at the bottom of a ramp? Along the floor?

Hypothesis

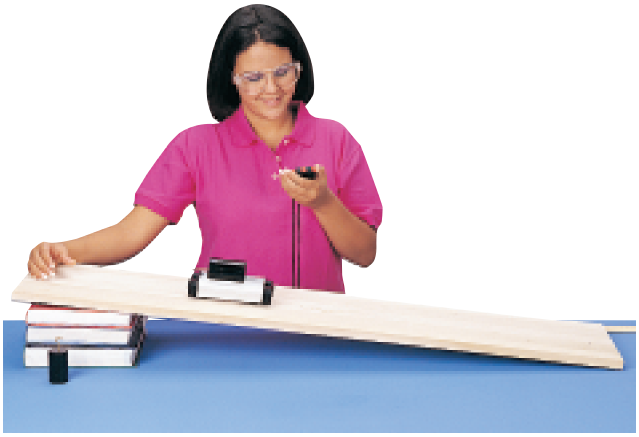
Form a hypothesis that relates the speed or energy of the cart at the bottom of the ramp to the mass of the cart on the ramp.

Possible Materials

cart
0.50-kg mass
1.0-kg mass
board to be used as a ramp
stopwatch
meterstick
masking tape

Plan the Experiment

1. Your lab group should develop a plan to answer the questions stated in the problem. How should you structure your investigation? How many trials do you need for each setup? Be prepared to present and defend your plan, data, and results to the class.
2. Identify the independent and dependent variables. Which will you keep constant?
3. Describe your procedures.
4. Describe the energy changes as the cart rolls down the ramp and onto the floor.
5. Construct data tables or spreadsheets that will show the measurements that you make.
6. **Check the Plan** Make sure your teacher has approved your plan before you proceed with your experiment.
7. When you have completed the lab, dispose of, recycle, or put away your materials.



Analyze and Conclude

1. **Checking Your Hypothesis** Did the speed at the bottom of the ramp depend on the mass of the cart? Does twice the mass have twice the speed? Does three times the mass go three times as fast?
2. **Calculating Results** List and explain the equations that you used for your energy calculations. What do the equations suggest about the speed at the bottom when the mass is changed?
3. **Comparing and Contrasting** Compare the gravitational potential energy of the cart at the starting position to the kinetic energy of the cart along the floor. What is your conclusion?
4. **Thinking Critically** Suppose one lab group finds that the cart has 30% more kinetic energy along the floor than the starting gravitational potential energy. What would you tell the group?

Apply

1. A Soap Box Derby is a contest in which riders coast down a long hill. Does the mass of the cart have a significant effect on the results? Predict what other factors may be more important in winning the race.

11.2 Conservation of Energy

You have read that when you consider a ball and Earth as a system, the sum of gravitational potential energy and kinetic energy in that system is constant. As the height of the ball changes, energy is converted from kinetic to potential energy and back again, but the total amount of energy stays the same. Conservation of energy, unlike conservation of momentum, does not follow directly from Newton's laws. It is a separate fact of nature. But this fact wasn't easy to discover. Rather, the law of conservation of energy was discovered in the middle of the 1800s, more than 150 years after Newton's work had been published. Since that time, the law has survived another 150 years of questioning and probing by scientists in many fields.

OBJECTIVES

- **Solve** problems using the law of conservation of energy.
- **Analyze** collisions to find the change in kinetic energy.

Choosing a System

If you have ever observed energy in action around you, you may have noticed that energy doesn't always seem to be conserved. The kinetic energy of a rolling soccer ball is soon gone. Even on smooth ice, a hockey puck eventually stops moving. The swings of a pendulum soon die away. To get an idea of what is happening, let's go back to the money model.

Suppose you had a total of $100 in cash and in the bank. One day, you counted your money and, despite neither earning nor spending anything, you were 50¢ short. Would you assume that the money just disappeared? Probably not. More likely, you'd go hunting through your purse or pants pockets trying to locate the lost change. If you couldn't find it there, you might look under the couch cushions or even in the dryer. In other words, rather than giving up on the conservation of money, you would seek new and different places where it might be.

Scientists have done the same with the conservation of energy. Rather than concluding that energy is not conserved, they have discovered new forms into which energy can be converted. They have concluded that the **law of conservation of energy** is a description of nature. That is, as long as the system under investigation is closed so that objects do not move in and out, and as long as the system is isolated from external forces, then energy can only change form. The total amount of energy is constant. In other words, energy can be neither created nor destroyed. In a closed, isolated system, energy is conserved.

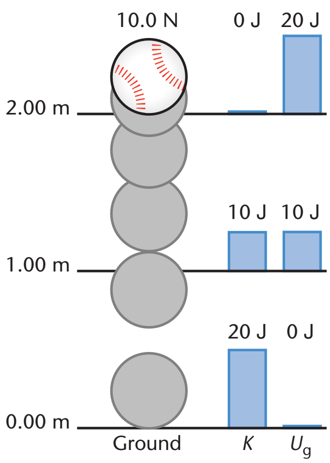


FIGURE 11–8 The decrease in potential energy is equal to the increase in kinetic energy.

Conservation of mechanical energy Although there are many forms of energy, you will be concerned only with kinetic and gravitational potential energy while investigating motion in this book. The sum of these forms of energy is referred to as **mechanical energy.** In any given system, *if no other forms of energy are present,*

Mechanical Energy $E = K + U_g.$

CONTENTS

Imagine a system consisting of a ball and Earth, as shown in **Figure 11–8.** Suppose the ball has a weight of 10.0 N and will be released 2.00 m above the ground, which you define to be the reference level. Because the ball isn't yet moving, it has no kinetic energy. Its potential energy is represented by the following.

$$U_g = mgh$$

$$U_g = (10.0 \text{ N})(2.00 \text{ m}) = 20.0 \text{ J}$$

The ball's total mechanical energy is therefore 20.0 J. As the ball falls, it loses potential energy and gains kinetic energy. When it is 1.00 m above Earth's surface, its potential energy is

$$U_g = mgh.$$

$$U_g = (10.0 \text{ N})(1.00 \text{ m}) = 10.0 \text{ J}$$

What is the ball's kinetic energy when it is at a height of 1.00 m? The system, which consists of the ball and Earth, is closed and, with no external forces acting upon it, is isolated. Thus, its total energy remains constant at 20.0 J.

$$E = K + U_g, \text{ so } K = E - U_g$$

$$K = 20.0 \text{ J} - 10.0 \text{ J} = 10.0 \text{ J}$$

When the ball reaches the ground, its potential energy is zero, and its kinetic energy is now the full 20.0 J. The equation that describes conservation of mechanical energy is $E_{\text{before}} = E_{\text{after}}$, which may be rewritten as follows.

Conservation of Mechanical Energy

$$K_{\text{before}} + U_{\text{g before}} = K_{\text{after}} + U_{\text{g after}}$$

What happens if the ball doesn't fall down, but rolls down a ramp, as shown in **Figure 11–9?** Without friction, there are still no net external forces, so the system is still closed and isolated. The ball still moves down a vertical distance of 2.00 m, so its loss of potential energy is still 20.0 J. Therefore, it still gains 20.0 J of kinetic energy. The path it takes doesn't matter.

In the case of a roller coaster that is nearly at rest at the top of the first hill, the total mechanical energy in the system is the coaster's gravitational potential energy at this point. Suppose some other hill along the track were higher than the first one. The roller coaster could not climb such a hill because doing so would require more mechanical energy than is in the system.

The simple oscillation of a pendulum also demonstrates the conservation of energy. The system is the pendulum bob plus Earth. Usually, the reference level is chosen to be the equilibrium position of the bob. Work is done by an external force in pulling the bob to one side. This gives the system mechanical energy. At the instant the bob is released, all the energy is potential; but as it swings down, the energy is converted to kinetic energy. When the bob is at the equilibrium point,

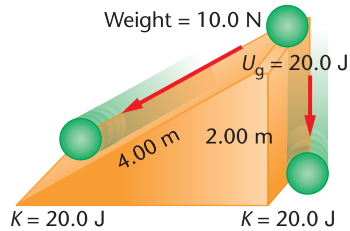


FIGURE 11–9 The path an object follows in reaching the ground does not affect the final kinetic energy of the object.

Whoosh!

Answers question from page 246.

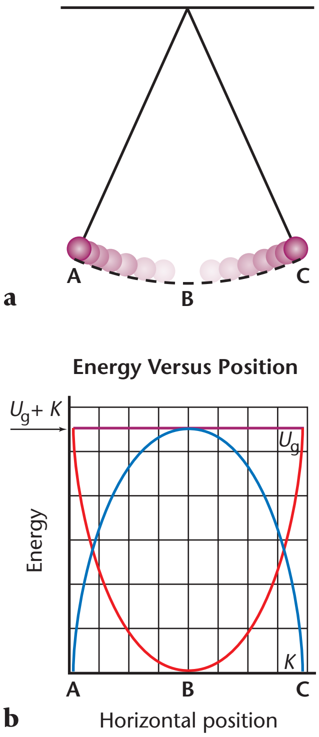


FIGURE 11–10 For the simple harmonic motion of a pendulum bob **(a),** the mechanical energy—the sum of the potential and kinetic energies—is a constant **(b).**

its gravitational potential energy is zero, and its kinetic energy is equal to the total mechanical energy in the system. **Figure 11–10** shows a graph of the changing potential and kinetic energy during one-half period of oscillation. Note that the mechanical energy is constant.

Loss of mechanical energy As you know, the oscillations of a pendulum eventually die away, a bouncing ball comes to rest, and the heights of roller-coaster hills get lower and lower. Where does the mechanical energy in such systems go? Any object moving through the air experiences the forces of air resistance. In a roller coaster, there are frictional forces in the wheels. When a ball bounces, the elastic potential energy stored in the deformed ball is not all converted back into kinetic energy after the bounce. In each of these cases, some of the original mechanical energy is converted into thermal energy within members of the system. As a result of the increased thermal energy, the temperature of the objects in the system will rise slightly. You will study this form of energy in Chapter 12.

Albert Einstein recognized yet another form of potential energy, mass itself. He said that mass, by its very nature, is energy. This energy, E_0, called the rest energy, is represented by the famous formula $E_0 = mc^2$. According to this equation, stretching a spring or bending a vaulting pole causes the spring or pole to gain mass. Likewise, a hot potato weighs more than a cold one. In these cases, the change in mass is too small to be detected. When forces within the nucleus of an atom are involved, however, the energy released into other forms, such as kinetic energy, by changes in mass can be relatively large.

PROBLEM SOLVING STRATEGIES

Conservation of Energy

When solving conservation of energy problems, use an orderly procedure.

1. Carefully identify the system. Make sure it is closed; that is, no objects enter or leave.
2. Identify the initial and final states of the system.
3. Is the system isolated?
   a. If there are no external forces acting on the system, then the total energy of the system is constant: $E_{before} = E_{after}$.
   b. If there are external forces, then $E_{before} + W = E_{after}$.
4. Identify the forms of energy in the system.
   a. If mechanical energy is conserved, then there is no thermal energy change. If it is not conserved, then the final thermal energy is larger than the initial thermal energy.
   b. Decide on the reference level for potential energy, and draw bar graphs showing initial and final energy.

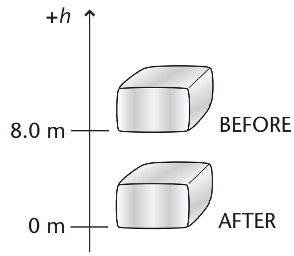
Example Problem

Conservation of Mechanical Energy

A large chunk of ice with mass 15.0 kg falls from a roof 8.00 m above the ground.

a. Ignoring air resistance, find the kinetic energy of the ice when it reaches the ground.

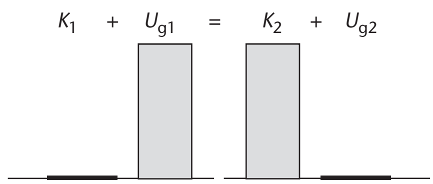
b. What is the speed of the ice when it reaches the ground?



Sketch the Problem

- Sketch the initial and final conditions.
- Choose a reference level.
- Draw a bar graph.

Calculate Your Answer



Known:

$m = 15.0$ kg $K_1 = 0$

$h = 8.00$ m $U_{g2} = 0$

$g = 9.80$ m/s^2

Unknown:

$U_{g1} = ?$

$K_2 = ?$

$v_2 = ?$

Strategy:

The system is the ice chunk plus Earth. With no external forces, it is isolated, so total energy is conserved. Falling does not significantly increase the thermal energy of the system, so mechanical energy is conserved and exists in two forms, kinetic and gravitational potential. Because the ice starts at rest and ends at the reference level, initial kinetic and final potential energies are zero. Thus, the initial potential energy equals the final kinetic energy.

Calculations:

a. $U_{g1} = mgh$

$= (15.0 \text{ kg})(9.80 \text{ m/s}^2)(8.00 \text{ m})$

$= 1.18 \times 10^3$ J

$K_2 = U_{g1} = 1.18 \times 10^3$ J

b. $K_2 = 1/2\, m{v_2}^2$

$$v_2 = \sqrt{\frac{2K_2}{m}} = \sqrt{\frac{2(1.18 \times 10^3 \text{ J})}{15.0 \text{ kg}}}$$

$= 12.5$ m/s

Check Your Answer

- Are your units correct? Velocity is in m/s and energy is in kg·m^2/s^2 = J.
- Do the signs make sense? K and speed are always positive.
- Is the magnitude realistic? Check with ${v_2}^2 = {v_1}^2 + 2ad$ from Newton's laws. $v_2 = \sqrt{2gh} = \sqrt{2(9.80 \text{ m/s}^2)(8.00 \text{ m})} = 12.5$ m/s

Practice Problems

9. A bike rider approaches a hill at a speed of 8.5 m/s. The mass of the bike and rider together is 85 kg.

a. Identify a suitable system.

Continued on next page

b. Find the initial kinetic energy of the system.
c. The rider coasts up the hill. Assuming that there is no friction, at what height will the bike come to rest?
d. Does your answer to **c** depend on the mass of the system? Explain.

10. Tarzan, mass 85 kg, swings down on the end of a 20-m vine from a tree limb 4.0 m above the ground. Sketch the situation.
a. How fast is Tarzan moving when he reaches the ground?
b. Does your answer to **a** depend on Tarzan's mass?
c. Does your answer to **a** depend on the length of the vine?

11. A skier starts from rest at the top of a 45-m hill, skis down a 30° incline into a valley, and continues up a 40-m-high hill. Both hill heights are measured from the valley floor. Assume that you can neglect friction and the effect of ski poles.
a. How fast is the skier moving at the bottom of the valley?
b. What is the skier's speed at the top of the next hill?
c. Does your answer to **a** or **b** depend on the angles of the hills?

12. Suppose, in the case of problem 9, that the bike rider pedaled up the hill and never came to a stop.
a. In what system is energy conserved?
b. From what form of energy did the bike gain mechanical energy?

Pocket Lab

Energy Exchange

Wear goggles for this activity. Select several different-sized steel balls and determine their masses. Stand a spring-loaded laboratory cart on end with the spring mechanism pointing upward. Place a ball on top of the spring mechanism. Press down on the ball to compress the spring until the ball is touching the cart. Quickly release the ball so that the spring shoots it upward. Repeat several times, and measure the average height. Predict how high the other sizes of steel balls should go. Try it. Record the values in a data table.

Analyze and Conclude Classify the balls in order of height attained. What conclusions can you reach?

Analyzing Collisions

In a system containing two objects, collisions sometimes occur. How can you analyze a collision between two objects? The details of a collision can be very complex, so you should find the motion of the objects just before and just after the collision. What conservation laws can be used to analyze such a system? If there are no external forces—that is, the system is isolated—then momentum is conserved. Energy also is conserved, but the potential energy or thermal energy could decrease,

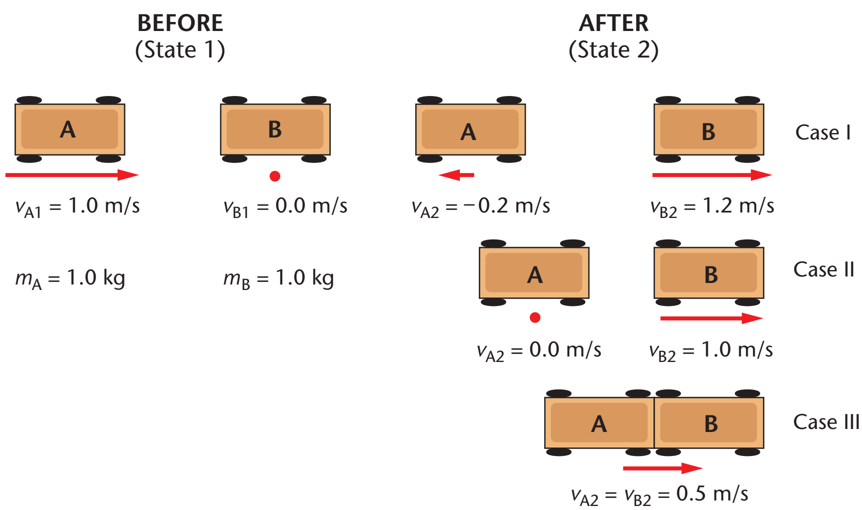


FIGURE 11–11 The energy considerations in these three kinds of collisions between a moving object and a stationary object are different. In Case I, the two objects move apart in opposite directions. In Case II, the moving object comes to rest, and the stationary object begins to move. In Case III, the two objects stick together and move as one.

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remain the same, or increase. Therefore, you cannot tell whether or not kinetic energy is conserved. **Figure 11–11** shows three different kinds of collisions, labeled Cases I, II, and III. Let's check the laws of conservation of momentum and energy using the data given for these three cases.

Is momentum conserved in each kind of collision? The momentum of the system before and after the collision is represented as

$$p_1 = p_{A1} + p_{B1} = (1.0\ \text{kg})(1.0\ \text{m/s}) + (1.0\ \text{kg})(0.0\ \text{m/s}) = 1.0\ \text{kg·m/s}$$

$$p_2 = p_{A2} + p_{B2} = (1.0\ \text{kg})(-0.2\ \text{m/s}) + (1.0\ \text{kg})(1.2\ \text{m/s}) = 1.0\ \text{kg·m/s}.$$

Thus, in Case I, the momentum is conserved. You can check to see if the momentum is conserved in the other two cases.

Is kinetic energy conserved in each of these cases? The kinetic energy of the system before and after the collision is represented as

$$K_{A1} + K_{B1} = 1/2(1.0\ \text{kg})(1.0\ \text{m/s})^2 + 1/2(1.0\ \text{kg})(0.0\ \text{m/s})^2 = 0.50\ \text{J}$$

$$K_{A2} + K_{B2} = 1/2(1.0\ \text{kg})(-0.2\ \text{m/s})^2 + 1/2(1.0\ \text{kg})(1.2\ \text{m/s})^2 = 0.74\ \text{J}.$$

The kinetic energy increased in Case I. How could this be? If energy is conserved, then one or more other forms of energy of the system must have decreased. Perhaps when the two carts collided, a compressed spring was released, adding kinetic energy to the system. This kind of collision sometimes is called super-elastic or explosive.

After the collision in Case II, the kinetic energy is represented as

$$K_{A2} + K_{B2} = 1/2(1.0\ \text{kg})(0.0\ \text{m/s})^2 + 1/2(1.0\ \text{kg})(1.0\ \text{m/s})^2 = 0.50\ \text{J}.$$

Kinetic energy remained the same. This kind of collision, in which the kinetic energy doesn't change, is called an **elastic collision.** Collisions between hard, elastic objects, such as those made of steel, glass, or hard plastic, are often nearly elastic.

After the collision in Case III, the kinetic energy is represented as

$$K_{A2} + K_{B2} = 1/2(1.0\ \text{kg})(0.5\ \text{m/s})^2 + 1/2(1.0\ \text{kg})(0.5\ \text{m/s})^2 = 0.25\ \text{J}.$$

Kinetic energy decreased; some kinetic energy was converted to thermal energy. This kind of collision, in which kinetic energy decreases, is called an **inelastic collision.** Objects made of soft, sticky material, such as clay, act in this way. When the two carts in Case III stuck together, they lost kinetic energy. Collisions are inelastic whenever kinetic energy is converted to thermal energy.

The three kinds of collisions can be represented using bar graphs, such as those shown in **Figure 11–12.** Although the kinetic energy before and after the collisions can be calculated, only the change in other forms of energy can be found. In automobile collisions, kinetic energy is transferred into other forms of energy such as heat and sound. These forms of energy are the result of bent metal, shattered glass, and cracked plastics. Unfortunately, you can't simply put the heat and sound back into the car and make it new again. Although you can recover the energy you put into gravitational potential energy, that is not the case for many other forms of energy.

EARTH SCIENCE CONNECTION

Fossil Fuels Fossil fuels—coal, oil, and natural gas—now supply about 86% of the energy consumed by industrial nations. Coal was formed when prehistoric swamp plants decayed; oil and natural gas were formed by the decay of tiny marine organisms. Millions of years ago, these living things were buried under tons of sediment and subjected to great pressure and heat. The energy that was trapped in the decayed organisms so long ago is released as heat and light when the fuels are burned.

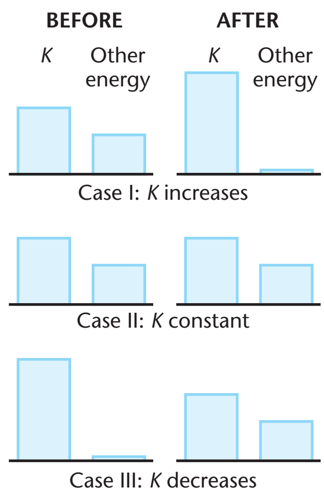


FIGURE 11–12 Bar graphs can be drawn to represent the three kinds of collisions.

Example Problem

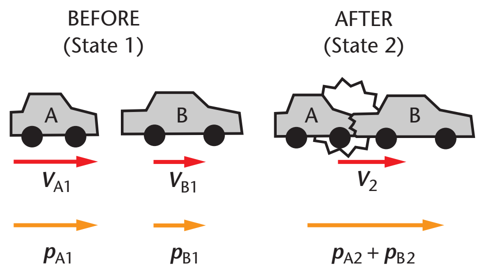
Kinetic Energy Loss in a Collision

In an accident on a slippery road, a compact car with mass 575 kg, moving at 15.0 m/s, smashes into the rear end of a car with mass 1575 kg moving at 5.00 m/s in the same direction.

a. What is the final velocity if the wrecked cars lock together?

b. How much kinetic energy was lost in the collision?

c. What fraction of the original kinetic energy was lost?



Sketch the Problem

- Sketch the initial and final conditions.
- Sketch the momentum diagram.

Calculate Your Answer

Known:

$m_A = 575$ kg

$v_{A1} = 15.0$ m/s

$m_B = 1575$ kg

$v_{B1} = 5.00$ m/s

$v_{A2} = v_{B2} = v_2$

Unknown:

$v_2 = ?$

$\Delta K = K_2 - K_1 = ?$

Fraction of K_1 lost, $\Delta K/K_1 = ?$

Strategy:

a. Use the conservation of momentum equation to find the final velocity.

Calculations:

$$p_{A1} + p_{B1} = p_{A2} + p_{B2}$$

$$m_A v_{A1} + m_B v_{B1} = (m_A + m_B)v_2$$

$$v_2 = \frac{m_A v_{A1} + m_B v_{B1}}{m_A + m_B}$$

$$= \frac{(575 \text{ kg})(15.0 \text{ m/s}) + (1575 \text{ kg})(5.00 \text{ m/s})}{575 \text{ kg} + 1575 \text{ kg}} = 7.67 \text{ m/s}$$

b. Determine the change in kinetic energy of the system.

$$\Delta K = K_2 - K_1$$

$$K_2 = 1/2(m_A + m_B)v_2^2 = 1/2(2150 \text{ kg})(7.67 \text{ m/s})^2 = 6.33 \times 10^4 \text{ J}$$

$$K_1 = 1/2 m_A v_{A1}^2 + 1/2 m_B v_{B1}^2$$

$$= 1/2(575 \text{ kg})(15.0 \text{ m/s})^2 + 1/2(1575 \text{ kg})(5.00 \text{ m/s})^2$$

$$= 8.44 \times 10^4 \text{ J}$$

$$\Delta K = 6.33 \times 10^4 \text{ J} - 8.44 \times 10^4 \text{ J} = -2.11 \times 10^4 \text{ J}$$

c. Use ΔK to calculate the fraction of the original kinetic energy lost.

$$\Delta K/K_1 = (-2.11 \times 10^4 \text{ J})/(8.44 \times 10^4 \text{ J}) = -0.250$$

25.0% was lost.

Check Your Answer

- Are the units correct? Velocity is in m/s; energy is in J.
- Does the sign make sense? Velocity is positive, consistent with the original velocities.
- Is the magnitude realistic? v_2 is faster than v_{B1}. Energies are typical of moving cars.

Practice Problems

13. A 2.00-g bullet, moving at 538 m/s, strikes a 0.250-kg piece of wood at rest on a frictionless table. The bullet sticks in the wood, and the combined mass moves slowly down the table.
a. Draw energy bar graphs and momentum vectors for the collision.
b. Find the speed of the system after the collision.
c. Find the kinetic energy of the system before the collision.
d. Find the kinetic energy of the system after the collision.
e. What percentage of the system's original kinetic energy was lost?

14. An 8.00-g bullet is fired horizontally into a 9.00-kg block of wood on an air table and is embedded in it. After the collision, the block and bullet slide along the frictionless surface together with a speed of 10.0 cm/s. What was the initial speed of the bullet?

15. Bullets can't penetrate Superman's chest. Suppose that Superman, with mass 104 kg, while not moving, is struck by a 4.20-g bullet moving with a speed of 835 m/s. The bullet drops straight down with no horizontal velocity. How fast was Superman moving after the collision if his superfeet are frictionless?

16. A 0.73-kg magnetic target is suspended on a string. A 0.025-kg magnetic dart, shot horizontally, strikes it head-on. The dart and the target together, acting like a pendulum, swing up 12 cm above the initial level before instantaneously coming to rest.
a. Sketch the situation and decide on the system.
b. This is a two-part problem. Decide what is conserved in each part and explain your decision.
c. What was the initial velocity of the dart?

11.2 Section Review

1. Is "spaceship Earth" a closed, isolated system? Support your answer.

2. A surfer crouches and moves high up into the curl of a wave. How is she using conservation of energy?

3. A child jumps on a trampoline. Draw bar graphs to show what form energy is in when
a. the child is at the highest point.
b. the child is at the lowest point.
c. the child's feet are just touching the trampoline.

4. **Critical Thinking** A ball drops 20 m. When it has fallen half the distance, or 10 m, half of its energy is potential and half is kinetic. When the ball has fallen instead for half the amount of time it takes to fall, will more, less, or exactly half of its energy be potential energy?

Physics & Society

Energy from Tides

Tides are the periodic rise and fall of the surface of a body of water. They result from the gravitational attraction among the sun, Earth, and its moon. When these bodies form a straight line in relation to each other, the effects of gravity are additive, and tidal ranges—the difference between high and low tides—are greatest. In regions where tidal ranges are at least 10 m, people are trying to harness the energy available in the tides to produce electricity.

Tidal power plants are built across estuaries, which are flooded river valleys that empty directly into an ocean. As an incoming tide arrives, the floodgates of a barrier near the mouth of the river are opened to capture the water. Then, as the tide ebbs, or recedes, the water exits the dam through turbines to generate electricity.

After three successful decades of operation, the La Rance tidal power plant in northern France produces 240 megawatts (MW) of electricity. The world's largest tidal power plant, the La Rance plant provides about 90 percent of the energy needs for this region of France. Eight trial tidal plants in China generate more than 6 MW of electricity. The newest plant in Jiangsu province provides residents in the Zhejiang province with 3.2 MW of power. Russia has built a pilot tidal plant with a capacity of 40 MW on the Barents Sea.

Tidal Energy—At What Cost?

For all energy resources, certain factors such as cost, environmental impact, availability, and wastes produced must be evaluated to determine whether or not the resource is feasible. Tidal power is relatively cheap. Electricity at La Rance is generated at about 3.7 cents per kilowatt hour (kWh). French nuclear plants provide the same power at about 3.8 cents per kWh. Meanwhile, hydroelectric power plants produce electricity at about 3.2 cents per kWh.

Energy produced by tides is nonpolluting. Moreover, unlike nuclear resources, tidal power requires no hazardous fuel to produce the energy. Nor does tidal power require disposal of dangerous substances.

Like all methods of producing energy, however, tidal power does have its problems. The environmental impact can include changes in water temperatures that can be detrimental to marine plants and animals in tidal zones, and a decrease in the number of marine organisms and migrating birds to an area as a result of changes in tidal levels.

Investigating the Issue

1. **Acquiring Information** Find out more about how a tidal power plant produces electricity. Display your findings with sketches that detail how a plant operates.
2. **Debating the Issue** Research the cost, environmental impact, availability, and wastes produced for each of the following resources: nuclear energy, hydroelectric power, solar energy, and fossil fuels. Now debate whether or not you think tidal power plants are a plausible energy alternative.

CLICK HERE

PHYSICS Online

To find out more about tidal energy, visit the Glencoe Science Web site at **science.glencoe.com**

CHAPTER 11 REVIEW

Summary

Key Terms

11.1
- gravitational potential energy
- reference level
- elastic potential energy

11.2
- law of conservation of energy
- mechanical energy
- elastic collision
- inelastic collision

11.1 The Many Forms of Energy

- The kinetic energy of an object is proportional to its mass and the square of its velocity.
- When Earth is included in a system, the work done by gravity is replaced by gravitational potential energy.
- The gravitational potential energy of an object depends on the object's weight and its distance from Earth's surface.
- The sum of kinetic and potential energy is called mechanical energy.
- Elastic potential energy may be stored in an object as a result of its change in shape.

11.2 Conservation of Energy

- The total energy of a closed, isolated system is constant. Within the system, energy can change form, but the total amount of energy doesn't change.
- Momentum is conserved in collisions if the external force is zero. The mechanical energy may be unchanged or decreased by the collision, depending on whether the collision is elastic or inelastic.

Key Equations

11.1

$U_g = mgh$

11.2

$E = K + U_g$ $\qquad K_{\text{before}} + U_{\text{g before}} = K_{\text{after}} + U_{\text{g after}}$

Reviewing Concepts

Unless otherwise directed, assume that air resistance is negligible.

Section 11.1

1. Explain how work and a change in the form of energy are related.
2. What form of energy does a wound watch spring have? What form of energy does a running mechanical watch use? When a watch runs down, what has happened to the energy?
3. Explain how energy and force are related.
4. A ball is dropped from the top of a building. You choose the top to be the reference level, while your friend chooses the bottom. Do the two of you agree on
   a. the ball's potential energy at any point?
   b. the change in the ball's potential energy as a result of the fall?
   c. the kinetic energy of the ball at any point?
5. Can the kinetic energy of a baseball ever be negative? Explain without using a formula.
6. Can the gravitational potential energy of a baseball ever be negative? Explain without using a formula.
7. If a baseball's velocity is increased to three times its original velocity, by what factor does its kinetic energy increase?
8. Can a baseball have kinetic energy and gravitational potential energy at the same time? Explain.
9. One athlete lifts a barbell three times as high as another. What is the ratio of changes in potential energy in the two lifts?

Section 11.2

10. What energy transformations take place when an athlete is pole-vaulting?

11. The sport of pole-vaulting was drastically changed when the stiff, wooden pole was replaced by the flexible, fiberglass pole. Explain why.

12. You throw a clay ball at a hockey puck on ice. The ball sticks, and the puck moves slowly.
- **a.** Is momentum conserved in the collision? Explain.
- **b.** Is kinetic energy conserved? Explain.

13. Draw energy bar graphs for the following processes.
- **a.** An ice cube, initially at rest, slides down a frictionless slope.
- **b.** An ice cube, initially moving, slides up a frictionless slope and instantaneously comes to rest.

14. Describe the transformations from kinetic to potential energy and vise versa for a hilly roller coaster ride.

15. An earthquake can release energy to devastate a city. Where does this energy reside moments before the earthquake takes place?

16. A rubber ball is dropped from a height of 1.2 m. After striking the floor, the ball bounces to a height of 0.8 m.
- **a.** Has the energy of the ball changed as a result of the collision with the floor? Explain.
- **b.** How high a bounce would you observe if the collision were completely elastic?
- **c.** How high a bounce would you observe if the collision were completely inelastic?

17. A speeding car puts on its brakes and comes to a stop. The system includes the car, but not the road. Apply the work-energy theorem when
- **a.** the car's wheels do not skid.
- **b.** the brakes lock and the car wheels skid.

18. Describe how the kinetic energy and elastic potential energy are transformed into thermal energy in a bouncing rubber ball. Describe what happens to the motion of the ball.

Applying Concepts

19. A compact car and a trailer truck are both traveling at the same velocity. Which has more kinetic energy?

20. Carmen and Lisa have identical compact cars. Carmen drives on the freeway with a greater speed than Lisa does. Which car has more kinetic energy?

21. Carmen and Lisa have identical compact cars. Carmen is northbound on the freeway, while Lisa is traveling south at the same speed. Which car has more kinetic energy?

22. During a process, positive work is done on a system, and the potential energy decreases. Can you determine anything about the change in kinetic energy of the system? Explain.

23. During a process, positive work is done on a system, and the potential energy increases. Can you tell whether the kinetic energy increased, decreased, or remained the same? Explain.

24. Two bodies of unequal mass have the same kinetic energy and are moving in the same direction. If the same retarding force is exerted on each body, how will the stopping distances of the bodies compare?

25. Roads seldom go straight up a mountain; they wind around and go up gradually. Explain.

26. You swing a 625-g mass on the end of a 0.75-m string around your head in a nearly horizontal circle at constant speed.
- **a.** How much work is done on the mass by the tension of the string in one revolution?
- **b.** Is your answer to **a** in agreement with the work-energy theorem? Explain.

27. Give specific examples that illustrate the following processes.
- **a.** Work is done on a system, increasing kinetic energy with no change in potential energy.
- **b.** Potential energy is changed to kinetic energy with no work done on the system.
- **c.** Work is done on a system, increasing potential energy with no change in kinetic energy.
- **d.** Kinetic energy is reduced but potential energy is unchanged. Work is done by the system.

28. You have been asked to make a roller coaster more exciting. The owners want the speed at the bottom of the first hill doubled. How much higher must the first hill be built?

29. If you drop a tennis ball onto a concrete floor, it will bounce back farther than it will if you drop it onto a rug. Where does the lost mechanical energy go when the ball strikes the rug?

30. Most Earth satellites follow an elliptical path rather than a circular path around Earth. The value of U_g increases when the satellite moves farther from Earth. According to the law of conservation of energy, does a satellite have its greatest speed when it is closest to or farthest from Earth?

31. In mountainous areas, road designers build escape ramps to help trucks with failed brakes stop. These escape ramps are usually roads made of loose gravel that go uphill. Describe changes in energy forms when a fast-moving truck uses one of these escape ramps.

32. If two identical bowling balls are raised to the same height, one on Earth, the other on Mars, which has the larger potential energy increase?

33. What will be the largest possible kinetic energy of an arrow shot from a bow that has been pulled back so that it stores 50 J of elastic potential energy?

34. Two pendulums swing side-by-side. At the bottom of the swing, the speed of one is twice the speed of the other. Compare the heights of the bobs at the end of their swings.

35. In a baseball game, two pop-ups are hit in succession. The second rises twice as high as the first. Compare the speeds of the two balls when they leave the bat.

36. Two identical balls are thrown from the top of a cliff, each with the same speed. One is thrown straight up, the other straight down. How do the kinetic energies and speeds of the balls compare as they strike the ground?

37. A ball is dropped from the top of a tall building and reaches terminal velocity as it falls. Will the decrease in potential energy of the ball equal the increase in its kinetic energy? Explain.

Problems

Unless otherwise directed, assume that air resistance is negligible. Draw energy bar graphs to solve the problems.

Section 11.1

38. A 1600-kg car travels at a speed of 12.5 m/s. What is its kinetic energy?

39. A racing car has a mass of 1525 kg. What is its kinetic energy if it has a speed of 108 km/h?

40. Toni has a mass of 45 kg and is moving with a speed of 10.0 m/s.
- **a.** Find Toni's kinetic energy.
- **b.** Toni's speed changes to 5.0 m/s. Now what is her kinetic energy?
- **c.** What is the ratio of the kinetic energies in **a** and **b?** Explain the ratio.

41. Shawn and his bike have a total mass of 45.0 kg. Shawn rides his bike 1.80 km in 10.0 min at a constant velocity. What is Shawn's kinetic energy?

42. Ellen and Angela each has a mass of 45 kg, and they are moving together with a speed of 10.0 m/s.
- **a.** What is their combined kinetic energy?
- **b.** What is the ratio of their combined mass to Ellen's mass?
- **c.** What is the ratio of their combined kinetic energy to Ellen's kinetic energy? Explain.

43. In the 1950s, an experimental train that had a mass of 2.50×10^4 kg was powered across a level track by a jet engine that produced a thrust of 5.00×10^5 N for a distance of 509 m.
- **a.** Find the work done on the train.
- **b.** Find the change in kinetic energy.
- **c.** Find the final kinetic energy of the train if it started from rest.
- **d.** Find the final speed of the train if there were no friction.

44. A 14 700-N car is traveling at 25 m/s. The brakes are applied suddenly, and the car slides to a stop. The average braking force between the tires and the road is 7100 N. How far will the car slide once the brakes are applied?

45. A 15.0-kg cart is moving with a velocity of 7.50 m/s down a level hallway. A constant force of −10.0 N acts on the cart, and its velocity becomes 3.20 m/s.
- **a.** What is the change in kinetic energy of the cart?
- **b.** How much work was done on the cart?
- **c.** How far did the cart move while the force acted?

46. How much potential energy does Tim, with mass 60.0 kg, gain when he climbs a gymnasium rope a distance of 3.5 m?

47. A 6.4-kg bowling ball is lifted 2.1 m into a storage rack. Calculate the increase in the ball's potential energy.

48. Mary weighs 505 N. She walks down a flight of stairs to a level 5.50 m below her starting point. What is the change in Mary's potential energy?

49. A weight lifter raises a 180-kg barbell to a height of 1.95 m. What is the increase in the potential energy of the barbell?

50. A 10.0-kg test rocket is fired vertically from Cape Canaveral. Its fuel gives it a kinetic energy of 1960 J by the time the rocket engine burns all of the fuel. What additional height will the rocket rise?

51. Antwan raised a 12.0-N physics book from a table 75 cm above the floor to a shelf 2.15 m above the floor. What was the change in the potential energy of the system?

52. A hallway display of energy is constructed in which several people pull on a rope that lifts a block 1.00 m. The display indicates that 1.00 J of work is done. What is the mass of the block?

53. It is not uncommon during the service of a professional tennis player for the racket to exert an average force of 150.0 N on the ball. If the ball has a mass of 0.060 kg and is in contact with the strings of the racket for 0.030 s, what is the kinetic energy of the ball as it leaves the racket? Assume that the ball starts from rest.

54. Pam, wearing a rocket pack, stands on frictionless ice. She has a mass of 45 kg. The rocket supplies a constant force for 22.0 m, and Pam acquires a speed of 62.0 m/s.
  a. What is the magnitude of the force?
  b. What is Pam's final kinetic energy?

55. A 2.00×10^3-kg car has a speed of 12.0 m/s. The car then hits a tree. The tree doesn't move, and the car comes to rest.
  a. Find the change in kinetic energy of the car.
  b. Find the amount of work done in pushing in the front of the car.
  c. Find the size of the force that pushed in the front of the car by 50.0 cm.

56. A constant net force of 410 N is applied upward to a stone that weighs 32 N. The upward force is applied through a distance of 2.0 m, and the stone is then released. To what height, from the point of release, will the stone rise?

Section 11.2

57. A 98-N sack of grain is hoisted to a storage room 50 m above the ground floor of a grain elevator.
  a. How much work was required?
  b. What is the increase in potential energy of the sack of grain at this height?
  c. The rope being used to lift the sack of grain breaks just as the sack reaches the storage room. What kinetic energy does the sack have just before it strikes the ground floor?

58. A 20-kg rock is on the edge of a 100-m cliff.
  a. What potential energy does the rock possess relative to the base of the cliff?
  b. The rock falls from the cliff. What is its kinetic energy just before it strikes the ground?
  c. What speed does the rock have as it strikes the ground?

59. An archer puts a 0.30-kg arrow to the bowstring. An average force of 201 N is exerted to draw the string back 1.3 m.
  a. Assuming that all the energy goes into the arrow, with what speed does the arrow leave the bow?
  b. If the arrow is shot straight up, how high does it rise?

60. A 2.0-kg rock initially at rest loses 407 J of potential energy while falling to the ground.
  a. Calculate the kinetic energy that the rock gains while falling.
  b. What is the rock's speed just before it strikes the ground?

61. A physics book of unknown mass is dropped 4.50 m. What speed does the book have just before it hits the ground?

62. A 30.0-kg gun is resting on a frictionless surface. The gun fires a 50.0-g bullet with a muzzle velocity of 310.0 m/s.
  a. Calculate the momenta of the bullet and the gun after the gun is fired.
  b. Calculate the kinetic energy of both the bullet and the gun just after firing.

63. A railroad car with a mass of 5.0×10^5 kg collides with a stationary railroad car of equal mass. After the collision, the two cars lock together and move off at 4.0 m/s.

a. Before the collision, the first railroad car was moving at 8.0 m/s. What was its momentum?
b. What was the total momentum of the two cars after the collision?
c. What were the kinetic energies of the two cars before and after the collision?
d. Account for the loss of kinetic energy.

64. From what height would a compact car have to be dropped to have the same kinetic energy that it has when being driven at 1.00×10^2 km/h?

65. A steel ball has a mass of 4.0 kg and rolls along a smooth, level surface at 62 m/s.
a. Find its kinetic energy.
b. At first, the ball was at rest on the surface. A constant force acted on it through a distance of 22 m to give it the speed of 62 m/s. What was the magnitude of the force?

66. Kelli weighs 420 N, and she is sitting on a playground swing seat that hangs 0.40 m above the ground. Tom pulls the swing back and releases it when the seat is 1.00 m above the ground.
a. How fast is Kelli moving when the swing passes through its lowest position?
b. If Kelli moves through the lowest point at 2.0 m/s, how much work was done on the swing by friction?

67. Justin throws a 10.0-g ball straight down from a height of 2.0 m. The ball strikes the floor at a speed of 7.5 m/s. What was the initial speed of the ball?

68. Megan's mass is 28 kg. She climbs the 4.8-m ladder of a slide and reaches a velocity of 3.2 m/s at the bottom of the slide. How much work was done by friction on Megan?

69. A person weighing 635 N climbs up a ladder to a height of 5.0 m. Use the person and Earth as the system.
a. Draw energy bar graphs of the system before the person starts to climb the ladder and after the person stops at the top. Has the mechanical energy changed? If so, by how much?
b. Where did this energy come from?

Extra Practice **For more practice solving problems, go to Extra Practice Problems, Appendix B.**

Critical Thinking Problems

70. A golf ball with mass 0.046 kg rests on a tee. It is struck by a golf club with an effective mass of 0.220 kg and a speed of 44 m/s. Assuming that the collision is elastic, find the speed of the ball when it leaves the tee.

71. In a perfectly elastic collision, both momentum and mechanical energy are conserved. Two balls with masses m_A and m_B are moving toward each other with speeds v_A and v_B, respectively. Solve the appropriate equations to find the speeds of the two balls after the collision.

72. A 25-g ball is fired with an initial speed v_1 toward a 125-g ball that is hanging motionless from a 1.25-m string. The balls have a perfectly elastic collision. As a result, the 125-g ball swings out until the string makes an angle of 37° with the vertical. What was v_1?

Going Further

Critical Thinking One of the important concepts in golf, tennis, baseball, and other sports is follow-through. How can applying a force to a ball for the longest possible time affect the speed of the ball?

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