

**BIG Idea**

Every change that occurs requires energy.

4.1 The Nature of Energy

MAIN Idea There are different forms of energy, including potential energy and kinetic energy.

4.2 Conservation of Energy

MAIN Idea Energy cannot be created or destroyed, but only can change from one form to another.

A Big Lift

How does this pole vaulter go from standing at the end of a runway to climbing through the air? The answer is energy. During her vault, energy originally stored in her muscles is converted into other forms of energy that enable her to soar.

Science Journal

Which takes more energy: walking up stairs or taking an escalator? Explain your reasoning.

Energy



Start-Up Activities



Energy Conversions

One of the most useful inventions of the nineteenth century was the electric lightbulb. Being able to light up the dark has enabled people to work and play longer. A lightbulb converts electrical energy to heat energy and light, another form of energy. The following lab shows how electrical energy is converted into other forms of energy.



WARNING: Steel wool can become hot—connect to battery only for a brief time.

1. Obtain two D-cell batteries, two non-coated paper clips, tape, metal tongs and some steel wool. Separate the steel wool into thin strands and straighten the paper clips.
2. Tape the batteries together and then tape one end of each paper clip to the battery terminals.
3. While holding the steel wool with the tongs, briefly complete the circuit by placing the steel wool in contact with both the paper clip ends.
4. **Think Critically** In your Science Journal, describe what happened to the steel wool. What changes did you observe?

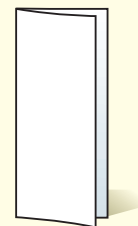


Preview this chapter's content and activities at gpscience.com

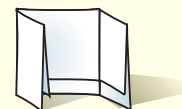
FOLDABLES™ Study Organizer

Energy Make the following Foldable to help you identify what you already know, what you want to know, and what you learned about energy.

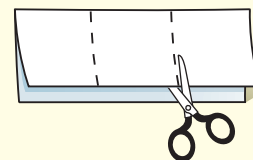
- STEP 1** **Fold** a vertical sheet of paper from side to side. Make the front edge about 1 cm shorter than the back edge.



- STEP 2** **Turn** lengthwise and **fold** into thirds.



- STEP 3** **Unfold and cut** only the top layer along both folds to make three tabs.



- STEP 4** **Label** each tab as shown.



Question Before you read this chapter, write what you already know about energy under the left tab of your Foldable, and write questions about what you'd like to know under the center tab. After you read the chapter, list what you learned under the right tab.



The Nature of Energy

Reading Guide

What You'll Learn

- **Distinguish** between kinetic and potential energy.
- **Calculate** kinetic energy.
- **Describe** different forms of potential energy.
- **Calculate** gravitational potential energy.

Why It's Important

All of the changes that occur around you every day involve the conversion of energy from one form to another.



Review Vocabulary

gravity: the attractive force between any two objects that have mass

New Vocabulary

- kinetic energy
- joule
- potential energy
- elastic potential energy
- chemical potential energy
- gravitational potential energy

Figure 1 The baseball caused changes to occur when it hit the window.

Describe the changes that are occurring.



What is energy?

Wherever you are sitting as you read this, changes are taking place—lightbulbs are heating the air around them, the wind might be rustling leaves, or sunlight might be glaring off a nearby window. Even you are changing as you breathe, blink, or shift position in your seat.

Every change that occurs—large or small—involves energy. Imagine a baseball flying through the air. It hits a window, causing the glass to break as shown in **Figure 1**. The window changed from a solid sheet of glass to a number of broken pieces. The moving baseball caused this change—a moving baseball has energy. Even when you comb your hair or walk from one class to another, energy is involved.

Change Requires Energy When something is able to change its environment or itself, it has energy. Energy is the ability to cause change. The moving baseball had energy. It certainly caused the window to change. Anything that causes change must have energy. You use energy to arrange your hair to look the way you want it to. You also use energy when you walk down the halls of your school between classes or eat your lunch. You even need energy to yawn, open a book, and write with a pen.



Different Forms of Energy

Turn on an electric light, and a dark room becomes bright. Turn on your CD player, and sound comes through your headphones.

In both situations, energy moves from one place to another. These changes are different from each other, and differ from the baseball shattering the window in **Figure 1**. This is because energy has several different forms—electrical, chemical, radiant, and thermal.

Figure 2 shows some examples of everyday situations in which you might notice energy. Is the chemical energy stored in food the same as the energy that comes from the Sun or the energy stored in gasoline? Radiant energy from the Sun travels a vast distance through space to Earth, warming the planet and providing energy that enables green plants to grow. When you make toast in the morning, you are using electrical energy. In short, energy plays a role in every activity that you do.



Reading Check

What are some different forms of energy?

An Energy Analogy Money can be used in an analogy to help you understand energy. If you have \$100, you could store it in a variety of forms—cash in your wallet, a bank account, travelers' checks, or gold or silver coins. You could transfer that money to different forms. You could deposit your cash into a bank account or trade the cash for gold. Regardless of its form, money is money. The same is true for energy. Energy from the Sun that warms you and energy from the food that you eat are only different forms of the same thing.



Figure 2 Energy can be stored and it can move from place to place.

Infer which materials are storing chemical energy.



Topic: Glacier Flow

Visit gpscience.com for Web links to information about the speeds at which glaciers flow.

Activity For the five fastest glaciers, calculate the kinetic energy a 1 kg block of ice in each glacier would have.

Kinetic Energy

When you think of energy, you might think of action—or objects in motion, like the baseball that shatters a window. An object in motion does have energy. **Kinetic energy** is the energy a moving object has because of its motion. The kinetic energy of a moving object depends on the object's mass and its speed.

Kinetic Energy Equation

$$\text{kinetic energy (in joules)} = \frac{1}{2} \text{ mass (in kg)} \times [\text{speed (in m/s)}]^2$$

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

In this equation, the symbol v represents speed. The SI unit of energy is the joule, abbreviated J. If you drop a softball from a height of about 0.5 m, it has a kinetic energy of about 1J just before it hits the floor. According to the above equation, the unit J is equal to the combination of units $\text{kg m}^2/\text{s}^2$.

KINETIC ENERGY EQUATION

Solve for Kinetic Energy

A jogger with a mass of 60.0 kg is moving at a speed of 3.0 m/s. What is the jogger's kinetic energy?

1

This is what you know:

mass: $m = 60.0 \text{ kg}$

speed: $v = 3.0 \text{ m/s}$

2

This is what you need to find:

kinetic energy: KE

3

Use this formula:

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

4

Substitute:

the values of m and v
into the formula and multiply.

$$KE = \frac{1}{2} (60.0)(3.0)^2 = \frac{1}{2} (60.0)(9.0) = 270$$

5

Determine the units:

$$\begin{aligned} \text{units of } KE &= (\text{units of } m) \times (\text{units of } v)^2 \\ &= \text{kg} \times (\text{m/s})^2 = \text{kg} \cdot \text{m}^2/\text{s}^2 = \text{J} \end{aligned}$$

Answer: The jogger's kinetic energy is 270 J.



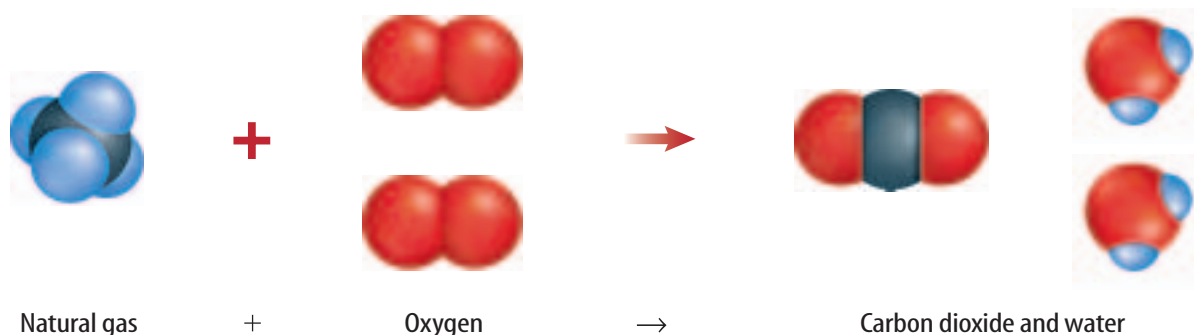
For more practice problems, go to page 834, and visit gpscience.com/extra_problems.

Practice Problems

1. A baseball with a mass of 0.15 kg is moving at a speed of 40 m/s. What is the baseball's kinetic energy?
2. A sprinter has a mass of 80.0 kg and a kinetic energy of 4,000 J. What is the sprinter's speed?
3. **Challenge** A car with a mass of 1,500 kg doubles its speed from 50 km/h to 100 km/h. By how many times does the kinetic energy of the car increase?



Figure 3 As natural gas burns, it combines with oxygen to form carbon dioxide and water. In this chemical reaction, chemical potential energy is released.



Potential Energy

Energy doesn't have to involve motion. Even motionless objects can have energy. This energy is stored in the object. Therefore, the object has potential to cause change. A hanging apple in a tree has stored energy. When the apple falls to the ground, a change occurs. Because the apple has the ability to cause change, it has energy. The hanging apple has energy because of its position above Earth's surface. Stored energy due to position is called **potential energy**. If the apple stays in the tree, it will keep the stored energy due to its height above the ground. If it falls, that stored energy of position is converted to energy of motion.

Elastic Potential Energy Energy can be stored in other ways, too. If you stretch a rubber band and let it go, it sails across the room. As it flies through the air, it has kinetic energy due to its motion. Where did this kinetic energy come from? Just as the apple hanging in the tree had potential energy, the stretched rubber band had energy stored as elastic potential energy. **Elastic potential energy** is energy stored by something that can stretch or compress, such as a rubber band or spring.

Chemical Potential Energy The cereal you eat for breakfast and the sandwich you eat at lunch also contain stored energy. Gasoline stores energy in the same way as food stores energy—in the chemical bonds between atoms. Energy stored in chemical bonds is **chemical potential energy**. **Figure 3** shows a molecule of natural gas. Energy is stored in the bonds that hold the carbon and hydrogen atoms together and is released when the gas is burned.



Reading Check

How is elastic potential energy different from chemical potential energy?



Interpreting Data from a Slingshot

Procedure

1. Using two fingers, carefully stretch a **rubber band** on a table until it has no slack.
2. Place a **nickel** on the table, slightly touching the mid-point of the rubber band.
3. Push the nickel back 0.5 cm into the rubber band and release. Measure the distance the nickel travels.
4. Repeat step 3, each time pushing the nickel back an additional 0.5 cm.

Analysis

1. How did the takeoff speed of the nickel depend on the distance that you stretched the rubber band?
2. How did the kinetic energy of the nickel depend on the distance the rubber band was stretched?



The Myth of Sisyphus In Greek mythology, a king named Sisyphus angered the gods by attempting to delay death. As punishment, he was doomed for eternity to endlessly roll a huge stone up a hill, only to have it roll back to the bottom again. Explain what caused the potential energy of the stone to change as it moved up and down the hill.

Gravitational Potential Energy Anything that can fall has stored energy called gravitational potential energy. **Gravitational potential energy** (GPE) is energy stored by objects due to their position above Earth's surface. The GPE of an object depends on the object's mass and height above the ground. Gravitational potential energy can be calculated from the following equation.

Gravitational Potential Energy Equation

$$\text{gravitational potential energy (J)} = \text{mass (kg)} \times \text{acceleration of gravity (m/s}^2\text{)} \times \text{height (m)}$$

$$GPE = mgh$$

In this equation, the acceleration of gravity has the symbol g . On Earth, the acceleration of gravity has the value 9.8 m/s^2 . Like all forms of energy, gravitational potential energy is measured in joules.

POTENTIAL ENERGY EQUATION

Solve for Gravitational Potential Energy What is the gravitational potential energy of a ceiling fan that has a mass of 7.0 kg and is 4.0 m above the ground?

- 1 **This is what you know:**

mass: $m = 7.0 \text{ kg}$
height: $h = 4.0 \text{ m}$
acceleration of gravity: $g = 9.8 \text{ m/s}^2$
- 2 **This is what you need to find:** gravitational potential energy: GPE
- 3 **Use this formula:** $GPE = mgh$
- 4 **Substitute:**

the values of m , g , and h
into the formula and multiply.

$$GPE = (7.0)(9.8)(4.0) = 274$$
- 5 **Determine the units:**

units of $GPE = (\text{units of } m) \times (\text{units of } g) \times (\text{units of } h)$
 $= \text{kg} \times \text{m/s}^2 \times \text{m} = \text{kg} \cdot \text{m}^2/\text{s}^2 = \text{J}$

Answer: The gravitational potential energy of the ceiling fan is 274 J .



For more practice problems, go to page 834, and visit gpscience.com/extra_problems.

Practice Problems

1. Find the GPE of a coffee mug with a mass of 0.3 that is on a counter top 1-m high above the ground.
2. How high above the ground is a baseball with a mass of 0.15 kg that has a GPE of 73.5 J ?
3. A rock climber is 200 m above the ground and has a GPE of $117,600 \text{ J}$. What is the rock climber's mass?
4. **Challenge** Suppose the mass of an object and its height above the ground both were to double. How would the object's gravitational potential energy change?



Changing GPE Look at the objects in the bookcase in **Figure 4**. Which of these objects has the most gravitational potential energy? According to the equation for gravitational potential energy, the GPE of an object can be increased by increasing its height above the ground. If two objects are at the same height, then the object with the larger mass has more gravitational potential energy.

In **Figure 4**, suppose the green vase on the lower shelf and the blue vase on the upper shelf have the same mass. Then the blue vase on the upper shelf has more gravitational potential energy because it is higher above the ground.

Imagine what would happen if the two vases were to fall. As they fall and begin moving, they have kinetic energy as well as gravitational potential energy. As the vases get closer to the ground, their gravitational potential energy decreases. At the same time, they are moving faster, so their kinetic energy increases. The vase that was higher above the floor has fallen a greater distance. As a result, the vase that initially had more gravitational potential energy will be moving faster and have more kinetic energy when it hits the floor.



Figure 4 An object's gravitational potential energy increases as its height increases.

section 1

review

Summary

Energy

- Energy is the ability to cause change.
- Forms of energy include electrical, chemical, thermal, and radiant energy.

Kinetic Energy

- Kinetic energy is the energy a moving object has because of its motion.
- The kinetic energy of a moving object can be calculated from this equation:

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

Potential Energy

- Potential energy is stored energy due to the position of an object.
- Different forms of potential energy include elastic potential energy, chemical potential energy, and gravitational potential energy.
- Gravitational potential energy can be calculated from this equation:

$$GPE = mgh$$

Self Check

1. **Explain** whether an object can have kinetic energy and potential energy at the same time.
2. **Describe** three situations in which the gravitational potential energy of an object changes.
3. **Explain** how the kinetic energy of a truck could be increased without increasing the truck's speed.
4. **Think Critically** The different molecules that make up the air in a room have on average the same kinetic energy. How does the speed of the different air molecules depend on their masses?

Applying Math

5. **Calculate Kinetic Energy** Find the kinetic energy of a ball with a mass of 0.06 kg moving at 50 m/s.
6. **Use Ratios** A boulder on top of a cliff has potential energy of 8,800 J, and has twice the mass of a boulder next to it. What is the GPE of the smaller boulder?
7. **Calculate GPE** An 80-kg diver jumps from a 10-m high platform. What is the gravitational potential energy of the diver halfway down?

Bouncing Balls

What happens when you drop a ball onto a hard, flat surface? It starts with potential energy. It bounces up and down until it finally comes to a rest. Where did the energy go?

Real-World Question

Why do bouncing balls stop bouncing?

Goals

- **Identify** the forms of energy observed in a bouncing ball.
- **Infer** why the ball stops bouncing.

Materials

tennis ball	masking tape
rubber ball	cardboard box
balance	* <i>shoe box</i>
meterstick	* <i>Alternate materials</i>

Safety Precautions



Procedure

1. **Measure** the mass of the two balls.
2. Have a partner drop one ball from 1 m. Measure how high the ball bounced. Repeat this two more times so you can calculate an average bounce height. Record your values on the data table.
3. Repeat step 2 for the other ball.
4. **Predict** whether the balls would bounce higher or lower if they were dropped onto the cardboard box. Design an experiment to measure how high the balls would bounce off the surface of a cardboard box.

Bounce Height

Type of Ball	Surface	Trial	Height (cm)
Tennis	Floor	1	
Tennis	Floor	2	
Tennis	Floor	3	
Rubber	Floor	1	
Rubber	Floor	2	
Rubber	Floor	3	
Tennis	Box	1	

Conclude and Apply

1. **Calculate** the gravitational potential energy of each ball before dropping it.
2. **Calculate** the average bounce height for the three trials under each condition. Describe your observations.
3. **Compare** the bounce heights of the balls dropped on a cardboard box with the bounce heights of the balls dropped on the floor. Hint: *Did you observe any movement of the box when the balls bounced?*
4. **Explain** why the balls bounced to different heights, using the concept of elastic potential energy.

Communicating Your Data

Meet with three other lab teams and compare average bounce heights for the tennis ball on the floor. Discuss why your results might differ. **For more help, refer to the Science Skill Handbook.**



Conservation of Energy

Reading Guide

What You'll Learn

- **Describe** how energy can be transformed from one form to another.
- **Explain** how the mechanical energy of a system is the sum of the kinetic and potential energy.
- **Discuss** the law of conservation of energy.

Why It's Important

All the energy transformations that occur inside you and around you obey the law of conservation of energy.

Review Vocabulary

friction: a force that opposes the sliding motion of two surfaces that are touching each other

New Vocabulary

- mechanical energy
- law of conservation of energy

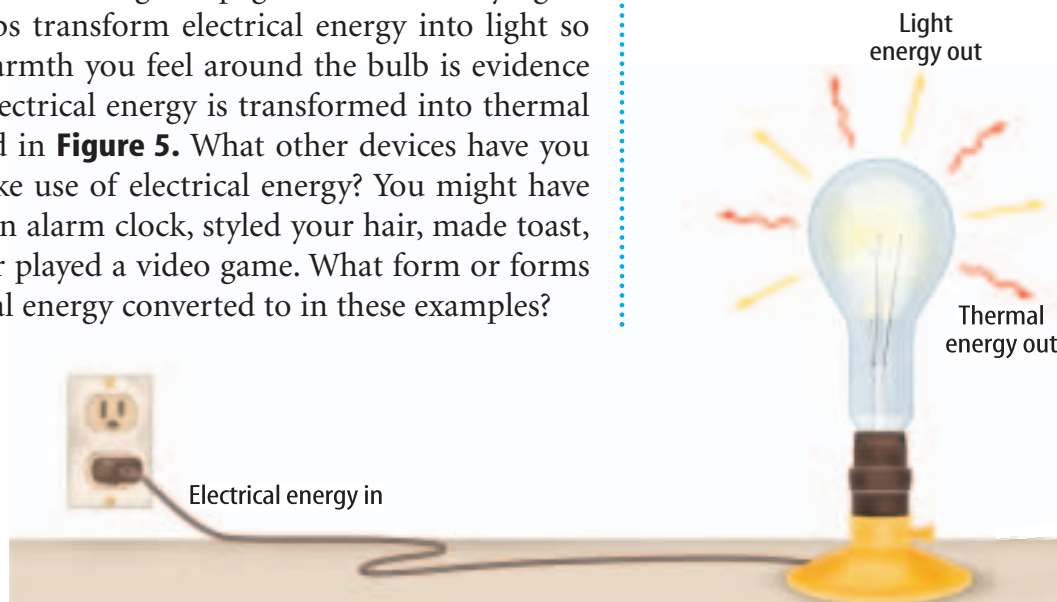
Changing Forms of Energy

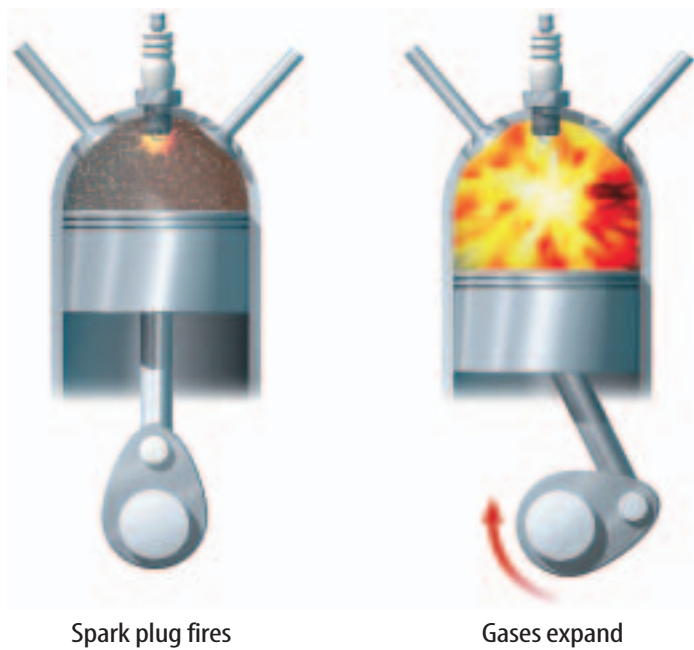
Unless you were talking about potential energy, you probably wouldn't think of the book on top of a bookshelf as having much to do with energy—until it fell. You'd be more likely to think of energy as race cars roar past or as your body uses energy from food to help it move, or as the Sun warms your skin on a summer day. These situations involve energy changing from one form to another form.

Transforming Electrical Energy You use many devices every day that convert one form of energy to other forms. For example, you might be reading this page in a room lit by lightbulbs. The lightbulbs transform electrical energy into light so you can see. The warmth you feel around the bulb is evidence that some of that electrical energy is transformed into thermal energy, as illustrated in **Figure 5**. What other devices have you used today that make use of electrical energy? You might have been awakened by an alarm clock, styled your hair, made toast, listened to music, or played a video game. What form or forms of energy is electrical energy converted to in these examples?

Figure 5 A lightbulb is a device that transforms electrical energy into light energy and thermal energy.

Identify other devices that convert electrical energy to thermal energy.





In a car, a spark plug fires, initiating the conversion of chemical potential energy into thermal energy.

Figure 6 In the engine of a car, several energy conversions occur.

As the hot gases expand, thermal energy is converted into kinetic energy.

Transforming Chemical Energy Fuel stores energy in the form of chemical potential energy. For example, the car or bus that might have brought you to school this morning probably runs on gasoline. The engine transforms the chemical potential energy stored in gasoline molecules into the kinetic energy of a moving car or bus. Several energy conversions occur in this process, as shown in **Figure 6**. An electric spark ignites a small amount of fuel. The burning fuel produces thermal energy. So chemical energy is changed to thermal energy. The thermal energy causes gases to expand and move parts of the car, producing kinetic energy.

Some energy transformations are less obvious because they do not result in visible motion, sound, heat, or light. Every green plant you see converts light energy from the Sun into energy stored in chemical bonds in the plant. If you eat an ear of corn, the chemical potential energy in the corn is transformed into other forms of energy by your body.

Conversions Between Kinetic and Potential Energy

You have experienced many situations that involve conversions between potential and kinetic energy. Systems such as bicycles, roller coasters, and swings can be described in terms of potential and kinetic energy. Even launching a rubber band or using a bow and arrow involves energy conversions. To understand the energy conversions that occur, it is helpful to identify the mechanical energy of a system. **Mechanical energy** is the total amount of potential and kinetic energy in a system and can be expressed by this equation.

$$\text{mechanical energy} = \text{potential energy} + \text{kinetic energy}$$

In other words, mechanical energy is energy due to the position and the motion of an object or the objects in a system. What happens to the mechanical energy of an object as potential and kinetic energy are converted into each other?



Falling Objects Standing under an apple tree can be hazardous. An apple on a tree, like the one in **Figure 7**, has gravitational potential energy due to Earth pulling down on it. The apple does not have kinetic energy while it hangs from the tree. However, the instant the apple comes loose from the tree, it accelerates due to gravity. As it falls, it loses height so its gravitational potential energy decreases. This potential energy is transformed into kinetic energy as the velocity of the apple increases.

Look back at the equation for mechanical energy. If the potential energy is being converted into kinetic energy, then the mechanical energy of the apple doesn't change as it falls. The potential energy that the apple loses is gained back as kinetic energy. The form of energy changes, but the total amount of energy remains the same.



Reading Check

What happens to the mechanical energy of the apple as it falls from the tree?

Energy Transformations in Projectile Motion Energy transformations also occur during projectile motion when an object moves in a curved path. Look at **Figure 8**. When the ball leaves the bat, it has mostly kinetic energy. As the ball rises, its velocity decreases, so its kinetic energy must decrease, too. However, the ball's gravitational potential energy increases as it goes higher. At its highest point, the baseball has the maximum amount of gravitational potential energy. The only kinetic energy it has at this point is due to its forward motion. Then, as the baseball falls, gravitational potential energy decreases while kinetic energy increases as the ball moves faster. However, the mechanical energy of the ball remains constant as it rises and falls.



Figure 7 Objects that can fall have gravitational potential energy.

Apply What objects around you have gravitational potential energy?



Figure 8 Kinetic energy and gravitational potential energy are converted into each other as the ball rises and falls.

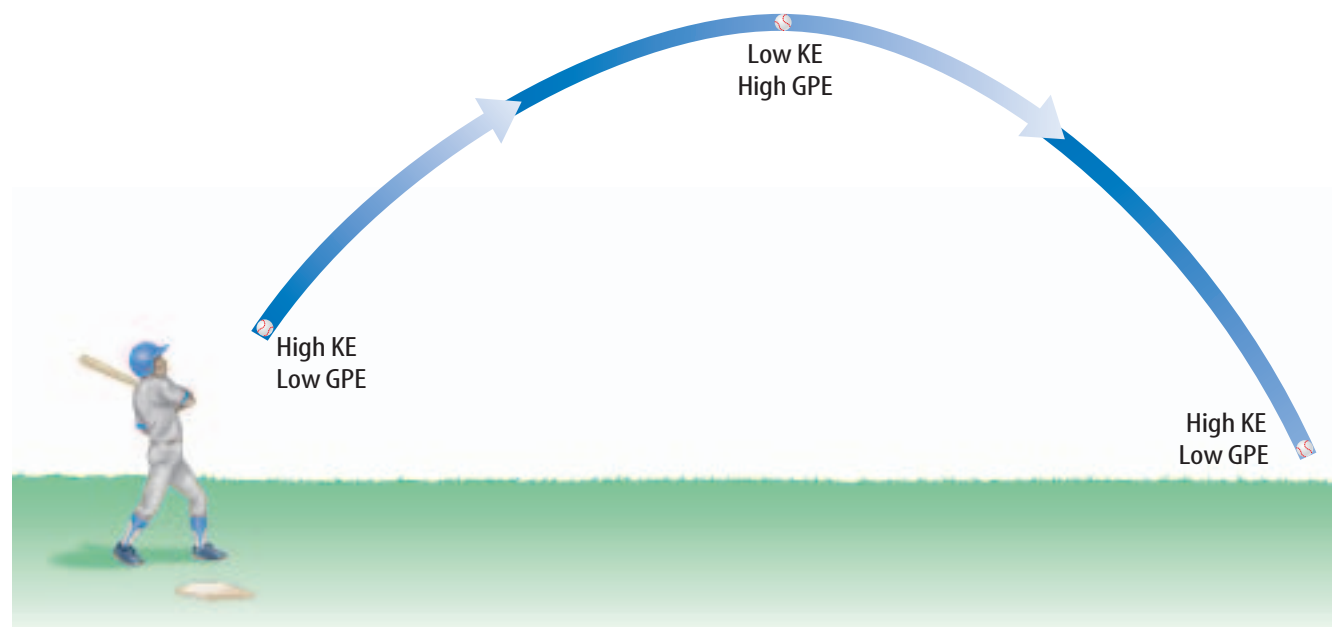
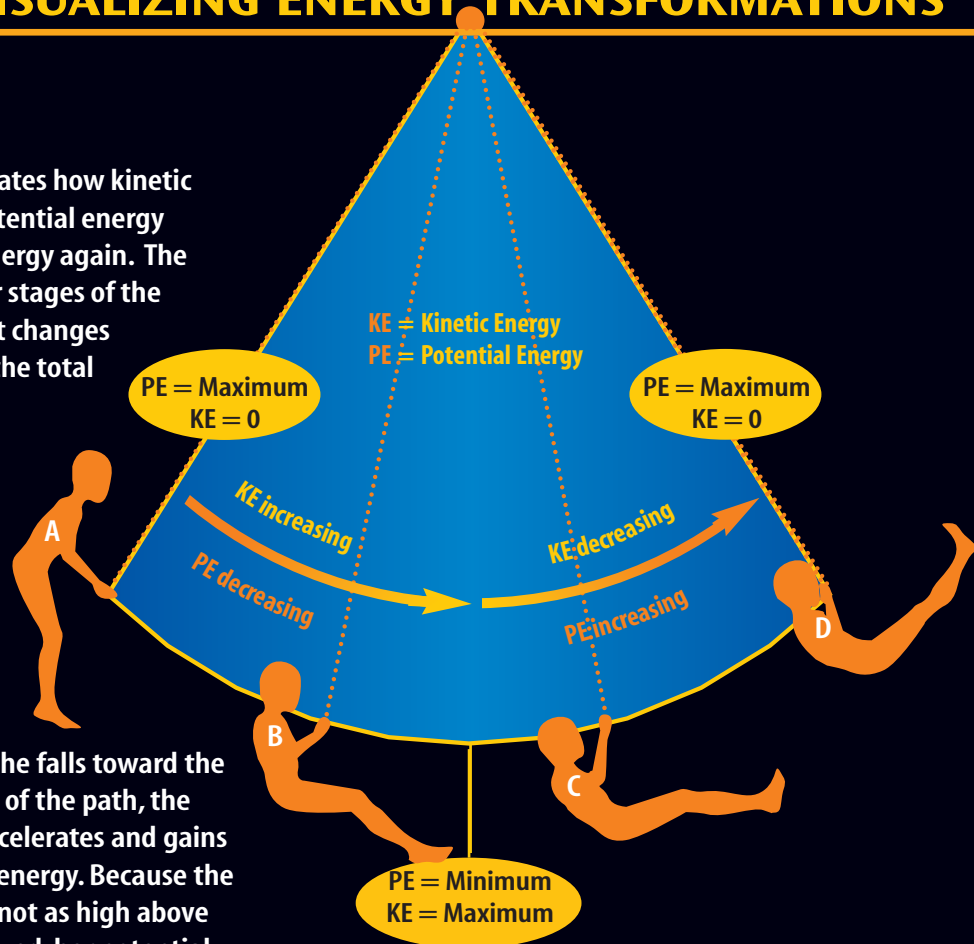




Figure 9

A ride on a swing illustrates how kinetic energy changes to potential energy and back to kinetic energy again. The diagram at right shows four stages of the swing's motion. Although it changes from one form to another, the total energy remains the same.

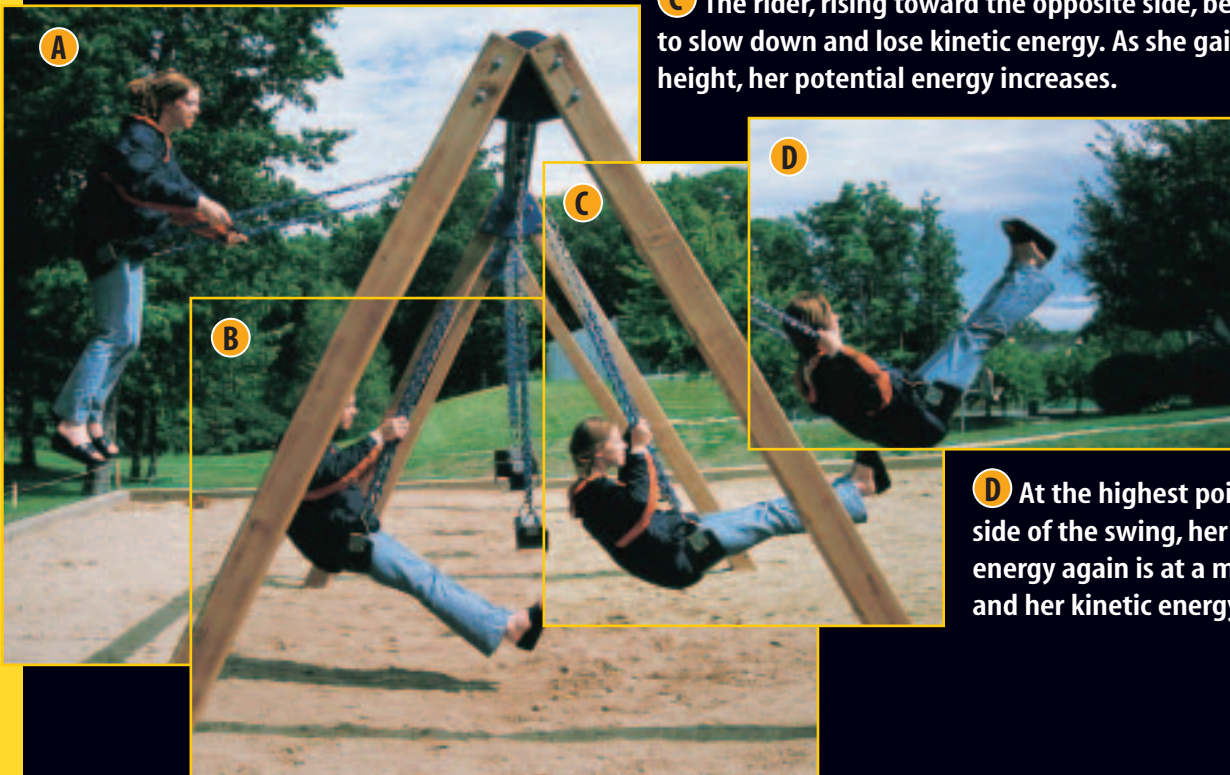


A At the rider's highest point, her potential energy is at a maximum and her kinetic energy is zero.

B As she falls toward the bottom of the path, the rider accelerates and gains kinetic energy. Because the rider is not as high above the ground, her potential energy decreases.

C The rider, rising toward the opposite side, begins to slow down and lose kinetic energy. As she gains height, her potential energy increases.

D At the highest point on this side of the swing, her potential energy again is at a maximum, and her kinetic energy is zero.





Energy Transformations in a Swing When you ride on a swing, like the one shown in **Figure 9**, part of the fun is the feeling of almost falling as you drop from the highest point to the lowest point of the swing's path. Think about energy conservation to analyze such a ride.

The ride starts with a push that gets you moving, giving you kinetic energy. As the swing rises, you lose speed but gain height. In energy terms, kinetic energy changes to gravitational potential energy. At the top of your path, potential energy is at its greatest. Then, as the swing accelerates downward, potential energy changes to kinetic energy. At the bottom of each swing, the kinetic energy is at its greatest and the potential energy is at its minimum. As you swing back and forth, energy continually converts from kinetic to potential and back to kinetic. What happens to your mechanical energy as you swing?

The Law of Conservation of Energy

When a ball is thrown into the air or a swing moves back and forth, kinetic and potential energy are constantly changing as the object speeds up and slows down. However, mechanical energy stays constant. Kinetic and potential energy simply change forms and no energy is destroyed.

This is always true. Energy can change from one form to another, but the total amount of energy never changes. Even when energy changes form from electrical to thermal and other energy forms as in the hair dryer shown in **Figure 10**, energy is never destroyed. Another way to say this is that energy is conserved. This principle is recognized as a law of nature. The **law of conservation of energy** states that energy cannot be created or destroyed. On a large scale, this law means that the total amount of energy in the universe does not change.



Reading Check

What law states that the total amount of energy never changes?

Conserving Resources You might have heard about energy conservation or been asked to conserve energy. These ideas are related to reducing the demand for electricity and gasoline, which lowers the consumption of energy resources such as coal and fuel oil. The law of conservation of energy, on the other hand, is a universal principle that describes what happens to energy as it is transferred from one object to another or as it is transformed.



Energy and the Food Chain

One way energy enters ecosystems is when green plants transform radiant energy from the Sun into chemical potential energy in the form of food. Energy moves through the food chain as animals that eat plants are eaten by other animals. Some energy leaves the food chain, such as when living organisms release thermal energy to the environment. Diagram a simple biological food chain showing energy conservation.

Figure 10 The law of conservation of energy requires that the total amount of energy going into a hair dryer must equal the total amount of energy coming out of the hair dryer.

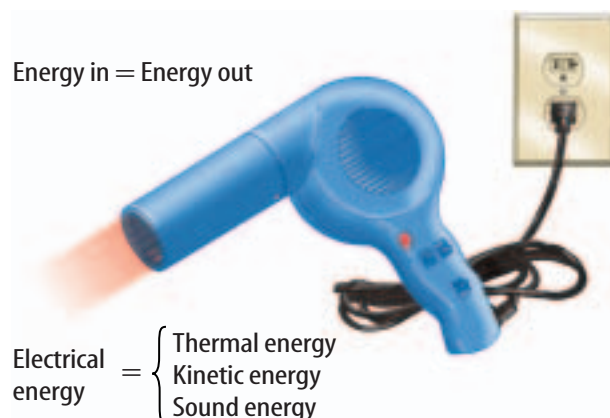
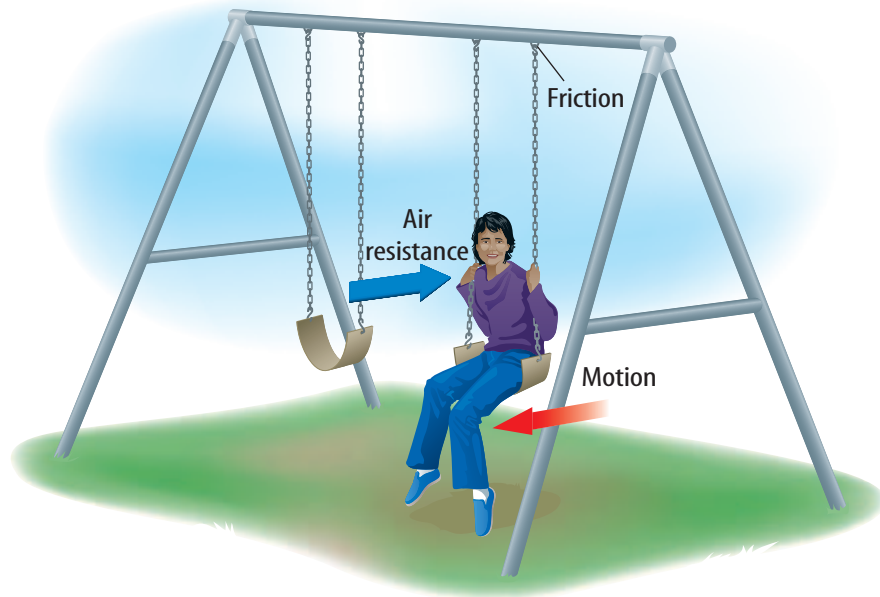




Figure 11 In a swing, mechanical energy is transformed into thermal energy because of friction and air resistance.

Infer how the kinetic and potential energy of the swing change with time.



Mini LAB

Energy Transformations in a Paper Clip

Procedure

1. Straighten a paper clip. While holding the ends, touch the paper clip to the skin just below your lower lip. Note whether the paper clip feels warm, cool, or about room temperature.
2. Quickly bend the paper clip back and forth five times. Touch it below your lower lip again. Note whether the paper clip feels warmer or cooler than before.

Analysis

1. What happened to the temperature of the paper clip? Why?
2. Explain the energy conversions that take place as you bend the paper clip.



Is energy always conserved? You might be able to think of situations where it seems as though energy is not conserved. For example, while coasting along a flat road on a bicycle, you know that you will eventually stop if you don't pedal. If energy is conserved, why wouldn't your kinetic energy stay constant so that you would coast forever? In many situations, it might seem that energy is destroyed or created. Sometimes it is hard to see the law of conservation of energy at work.

The Effect of Friction You know from experience that if you don't continue to pump a swing or be pushed by somebody else, your arcs will become lower and you eventually will stop swinging. In other words, the mechanical (kinetic and potential) energy of the swing seems to decrease, as if the energy were being destroyed. Is this a violation of the law of conservation of energy?

It can't be—it's the law! If the energy of the swing decreases, then the energy of some other object must increase by an equal amount to keep the total amount of energy the same. What could this other object be that experiences an energy increase? To answer this, you need to think about friction. With every movement, the swing's ropes or chains rub on their hooks and air pushes on the rider, as illustrated in **Figure 11**. Friction and air resistance cause some of the mechanical energy of the swing to change to thermal energy. With every pass of the swing, the temperature of the hooks and the air increases a little, so the mechanical energy of the swing is not destroyed. Rather, it is transformed into thermal energy. The total amount of energy always stays the same.



Converting Mass into Energy You might have wondered how the Sun unleashes enough energy to light and warm Earth from so far away. A special kind of energy conversion—nuclear fusion—takes place in the Sun and other stars. During this process a small amount of mass is transformed into a tremendous amount of energy. An example of a nuclear fusion reaction is shown in **Figure 12**. In the reaction shown here, the nuclei of the hydrogen isotopes deuterium and tritium undergo fusion.

Nuclear Fission Another process involving the nuclei of atoms, called nuclear fission, converts a small amount of mass into enormous quantities of energy. In this process, nuclei do not fuse—they are broken apart, as shown in **Figure 12**. In either process, fusion or fission, mass is converted to energy. In processes involving nuclear fission and fusion, the total amount of energy is still conserved if the energy content of the masses involved are included. Then the total energy before the reaction is equal to the total energy after the reaction, as required by the law of conservation of energy. The process of nuclear fission is used by nuclear power plants to generate electrical energy.

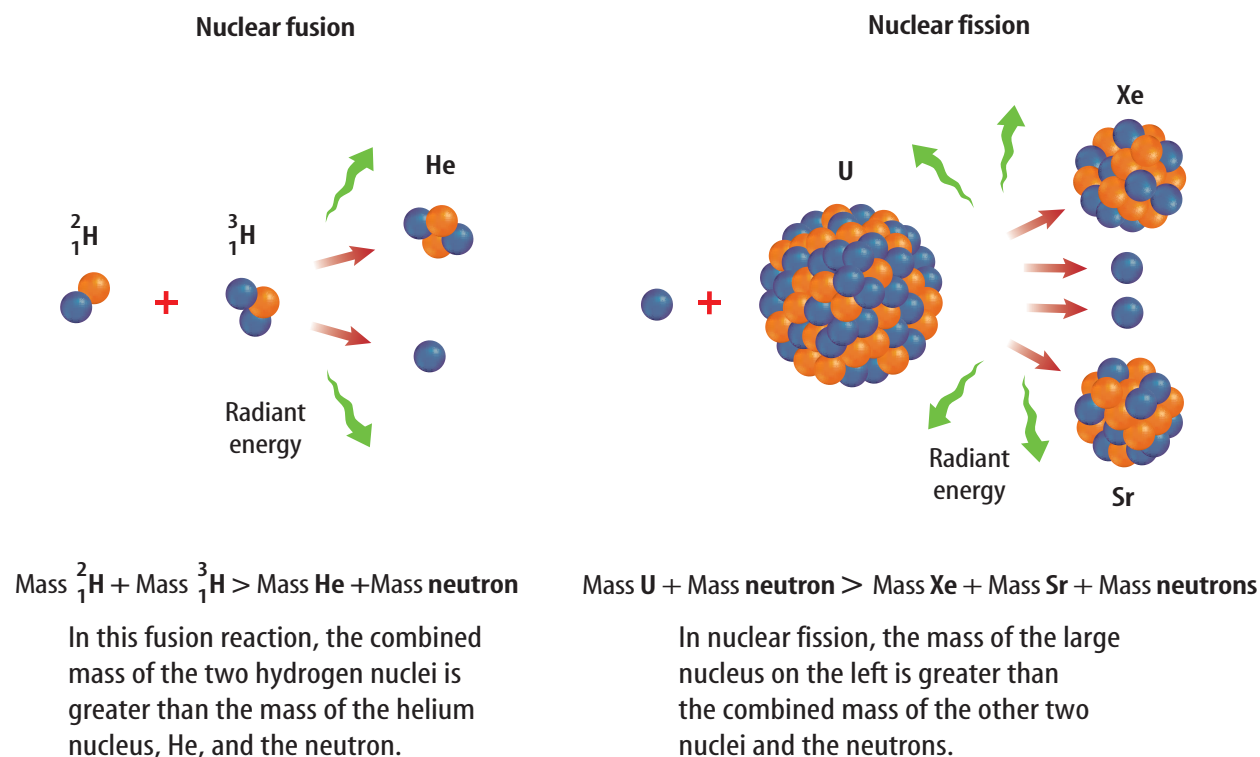


Topic: Nuclear Fusion

Visit gpscience.com for Web links to information about using nuclear fusion as a source of energy in electric power plants.

Activity Make a table listing the advantages and disadvantages of using nuclear fusion as an energy source.

Figure 12 Mass is converted to energy in the processes of fusion and fission.





The Human Body—Balancing the Energy Equation

What forms of energy discussed in this chapter can you find in the human body? With your right hand, reach up and feel your left shoulder. With that simple action, stored potential energy within your body was converted to the kinetic energy of your moving arm. Did your shoulder feel warm to your hand? Some of the chemical potential energy stored in your body is used to maintain a nearly constant internal temperature. A portion of this energy also is converted to the excess heat that your body gives off to its surroundings. Even the people shown standing in **Figure 13** require energy conversions to stand still.

Figure 13 The runners convert the energy stored in their bodies more rapidly than the spectators do.

Calculate Use **Table 1** to calculate how long a person would need to stand to burn as much energy as a runner burns in 1 h.

Energy Conversions in Your Body The complex chemical and physical processes going on in your body also obey the law of conservation of energy. Your body stores energy in the form of fat and other chemical compounds. This chemical potential energy is used to fuel the processes that keep you alive, such as making your heart beat and digesting the food you eat. Your body also converts this energy to heat that is transferred to your surroundings, and you use this energy to make your body move. **Table 1** shows the amount of energy used in doing various activities. To maintain a healthy weight, you must have a proper balance between energy contained in the food you eat and the energy your body uses.





Food Energy

Your body has been busy breaking down your breakfast into molecules that can be used as fuel. The chemical potential energy in these molecules supplies the cells in your body with the energy they need to function. Your body also can use the chemical potential energy stored in fat for its energy needs. The food Calorie (C) is a unit used by nutritionists to measure how much energy you get from various foods—1 C is equivalent to about 4,184 J. Every gram of fat a person consumes can supply 9 C of energy. Carbohydrates and proteins each supply about 4 C of energy per gram.

Look at the labels on food packages. They provide information about the Calories contained in a serving, as well as the amounts of protein, fat, and carbohydrates.

Table 1 Calories Used in 1 h

Type of Activity	Body Frames		
	Small	Medium	Large
Sleeping	48	56	64
Sitting	72	84	96
Eating	84	98	112
Standing	96	112	123
Walking	180	210	240
Playing tennis	380	420	460
Bicycling (fast)	500	600	700
Running	700	850	1,000

section 2 review

Summary

Energy Transformations

- Energy can be transformed from one form to another.
- Devices such as lightbulbs, hair dryers, and automobile engines convert one form of energy into other forms.
- The mechanical energy of a system is the sum of the kinetic and potential energy in the system:
$$\text{mechanical energy} = \text{KE} + \text{PE}$$
- In falling, projectile motion, and swings, kinetic and potential energy are transformed into each other and the mechanical energy doesn't change.

The Law of Conservation of Energy

- According to the law of conservation of energy, energy cannot be created or destroyed.
- Friction converts mechanical energy into thermal energy.
- Fission and fusion are nuclear reactions that convert a small amount of mass in a nucleus into an enormous amount of energy.

Self Check

1. **Explain** how friction affects the mechanical energy of a system.
2. **Describe** the energy transformations that occur as you coast down a long hill on a bicycle and apply the brakes, causing the brake pads and bicycle rims to feel warm.
3. **Explain** how energy is conserved when nuclear fission or fusion occurs.
4. **Think Critically** A roller coaster is at the top of a hill and rolls to the top of a lower hill. If mechanical energy is conserved, on the top of which hill is the kinetic energy of the roller coaster larger?

Applying Math

5. **Calculate Kinetic Energy** The potential energy of a swing is 200 J at its highest point and 50 J at its lowest point. If mechanical energy is conserved, what is the kinetic energy of the swing at its lowest point?
6. **Calculate Thermal Energy** The mechanical energy of a bicycle at the top of a hill is 6,000 J. The bicycle stops at the bottom of the hill by applying the brakes. If the potential energy of the bicycle is 2,000 J at the bottom of the hill, how much thermal energy was produced?

Swing[💡]ng Energy

Goals

- **Construct** a pendulum to compare the exchange of potential and kinetic energy when a swing is interrupted.
- **Measure** the starting and ending heights of the pendulum.

Possible Materials

ring stand
test-tube clamp
support-rod clamp, right angle
30-cm support rod
2-hole, medium rubber stopper
string (1 m)
metersticks
graph paper

Safety Precautions



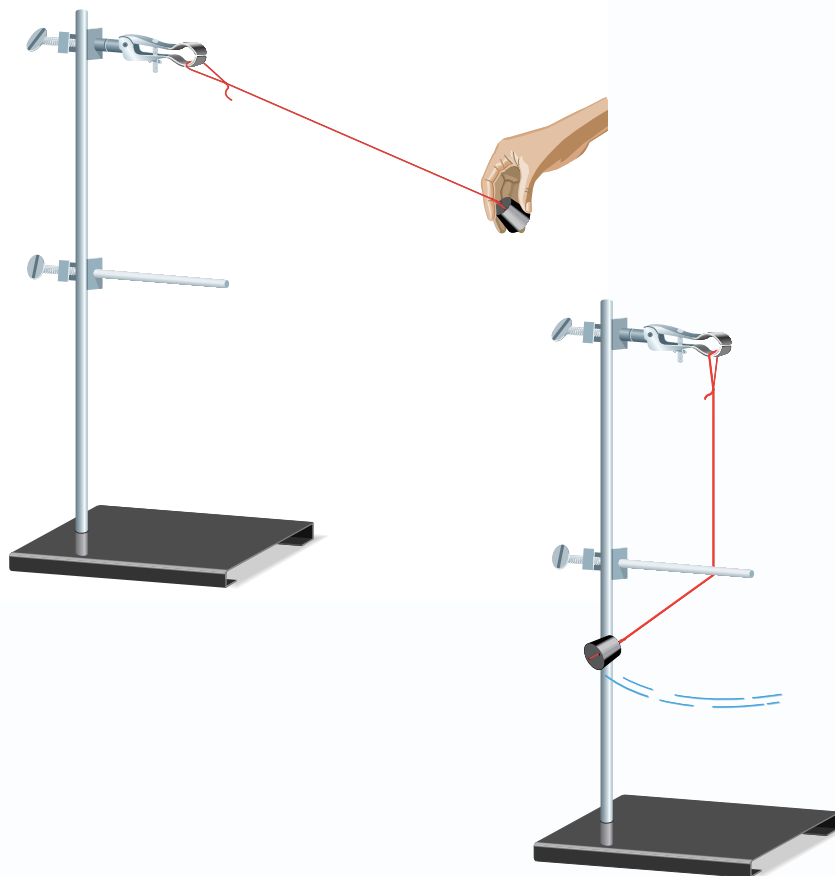
WARNING: Be sure the base is heavy enough or well anchored so that the apparatus will not tip over.

Real-World Question

Imagine yourself swinging on a swing. What would happen if a friend grabbed the swing's chains as you passed the lowest point? Would you come to a complete stop or continue rising to your previous maximum height? How does the motion and maximum height reached by a swing change if the swing is interrupted?

Form a Hypothesis

Examine the diagram on this page. How is it similar to the situation in the introductory paragraph? An object that is suspended so that it can swing back and forth is called a pendulum. Hypothesize what will happen to the pendulum's motion and final height if its swing is interrupted.



▶ Test Your Hypothesis

Make a Plan

1. As a group, write your hypothesis and list the steps that you will take to test it. Be specific. Also list the materials you will need.
2. **Design** a data table and place it in your Science Journal.
3. Set up an apparatus similar to the one shown in the diagram.
4. **Devise** a way to measure the starting and ending heights of the stopper. Record your starting and ending heights in a data table. This will be your control.
5. **Decide** how to release the stopper from the same height each time.
6. Be sure you test your swing, starting it above and below the height of the cross arm. How many times should you repeat each starting point?

Follow Your Plan

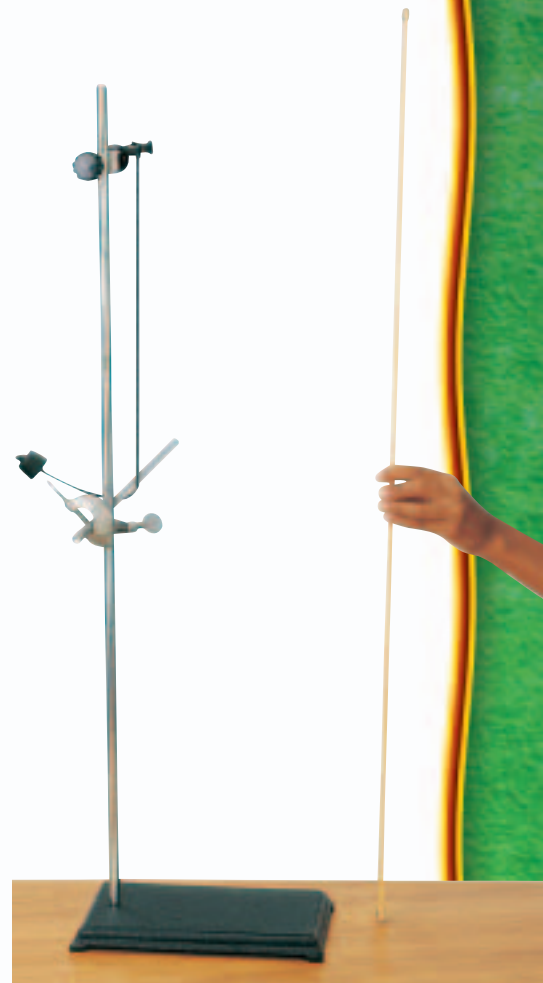
1. Make sure your teacher approves your plan before you start.
2. Carry out the approved experiment as planned.
3. While the experiment is going on, write any observations that you make and complete the data table in your Science Journal.

▶ Analyze Your Data

1. When the stopper is released from the same height as the cross arm, is the ending height of the stopper exactly the same as its starting height? Use your data to support your answer.
2. **Analyze** the energy transfers. At what point along a single swing does the stopper have the greatest kinetic energy? The greatest potential energy?

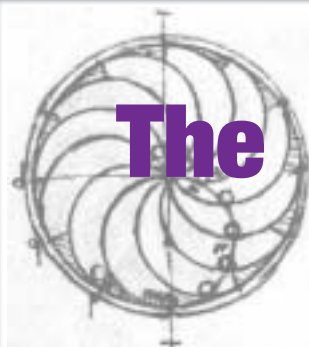
▶ Conclude and Apply

1. **Explain** Do the results support your hypothesis?
2. **Compare** the starting heights to the ending heights of the stopper. Is there a pattern? Can you account for the observed behavior?
3. **Discuss** Do your results support the law of conservation of energy? Why or why not?
4. **Infer** What happens if the mass of the stopper is increased? Test it.



Communicating Your Data

Compare your conclusions with those of the other lab teams in your class. **For more help, refer to the Science Skill Handbook.**



The Impossible Dream

**A machine that keeps on going?
It has been tried for hundreds of years.**

Many people have tried throughout history—and failed—to build perpetual-motion machines. In theory, a perpetual-motion machine would run forever and do work without a continual source of energy. You can think of it as a car that you could fill up once with gas, and the car would run forever. Sound impossible? It is!

Science Puts Its Foot Down

For hundreds of years, people have tried to create perpetual-motion machines. But these machines won't work because they violate two of nature's laws. The first law is the law of conservation of energy, which states that energy cannot be created or destroyed. It can change form—say,

from mechanical energy to electrical energy—but you always end up with the same amount of energy that you started with.

How does that apply to perpetual-motion machines? When a machine does work on an object, the machine transfers energy to the object.

Unless that machine gets more energy from somewhere else, it can't keep doing work. If it did, it would be creating energy.

The second law states that heat by itself always flows from a warm object to a cold object. Heat will only flow from a cold object to a warm object if work is done. In the process, some heat always escapes.

To make up for these energy losses, energy constantly needs to be transferred to the machine. Otherwise, it stops. No perpetual motion. No free electricity. No devices that generate more energy than they use. No engine motors that run forever without refueling. Some laws just can't be broken.

Visitors look at the Keely Motor, the most famous perpetual-motion machine fraud of the late 1800s.



Analyze Using your school or public-library resources, locate a picture or diagram of a perpetual-motion machine. Figure out why it won't run forever. Explain to the class what the problem is.

Science **online**

For more information, visit
gpscience.com/time

Reviewing Main Ideas

Section 1 The Nature of Energy

1. Energy is the ability to cause change.
2. Energy can have different forms, including kinetic, potential, and thermal energy.



3. Moving objects have kinetic energy that depends on the object's mass and velocity, and can be calculated from this equation:

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

4. Potential energy is stored energy. An object can have gravitational potential energy that depends on its mass and its height, and is given by this equation:

$$GPE = mgh$$

**Section 2 Conservation of Energy**

1. Energy can change from one form to another. Devices you use every day transform one form of energy into other forms that are more useful.
2. Falling, swinging, and projectile motion all involve transformations between kinetic energy and gravitational potential energy.
3. The total amount of kinetic energy and gravitational potential energy in a system is the mechanical energy of the system:

$$\text{mechanical energy} = KE + GPE$$
4. The law of conservation of energy states that energy never can be created or destroyed. The total amount of energy in the universe is constant.



5. Friction converts mechanical energy into thermal energy, causing the mechanical energy of a system to decrease.
6. Mass is converted into energy in nuclear fission and fusion reactions. Fusion and fission occur in the nuclei of certain atoms, and release tremendous amounts of energy.

FOLDABLES™

Use the Foldable you made at the beginning of this chapter to review what you learned about energy.

Using Vocabulary

chemical potential energy p. 103	joule p. 102
elastic potential energy p. 103	kinetic energy p. 102
gravitational potential energy p. 104	law of conservation of energy p. 111
	mechanical energy p. 108
	potential energy p. 103

Complete each statement using a word(s) from the vocabulary list above.

- If friction can be ignored, the _____ of a system doesn't change.
- The energy stored in a compressed spring is _____.
- The _____ is the SI unit for energy.
- When a book is moved from a higher shelf to a lower shelf, its _____ changes.
- The muscles of a runner transform chemical potential energy into _____.
- According to the _____ the amount of energy in the universe doesn't change.
- The gravitational potential energy of an object changes when which of the following changes?
 - the object's speed
 - the object's mass
 - the object's temperature
 - the object's length
- Friction causes mechanical energy to be transformed into which of these forms?
 - thermal energy
 - nuclear energy
 - kinetic
 - potential
- The kinetic energy of an object changes when which of the following changes?
 - the object's chemical potential energy
 - the object's volume
 - the object's direction of motion
 - the object's speed
- When an energy transformation occurs, which of the following is true?
 - Mechanical energy doesn't change.
 - Mechanical energy is lost.
 - The total energy doesn't change.
 - Mass is converted into energy.

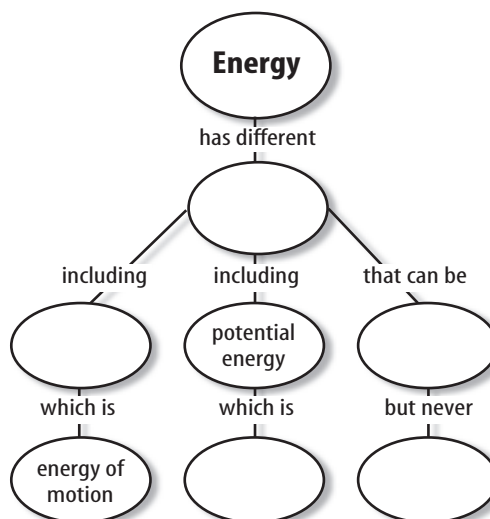
Checking Concepts

Choose the word or phrase that best answers the question.

- What occurs when energy is transferred from one object to another?
 - an explosion
 - a chemical reaction
 - nuclear fusion
 - a change
- For which of the following is kinetic energy converted into potential energy?
 - a boulder rolls down a hill
 - a ball is thrown upward
 - a swing comes to a stop
 - a bowling ball rolls horizontally

Interpreting Graphics

- Copy and complete the following concept map on energy.

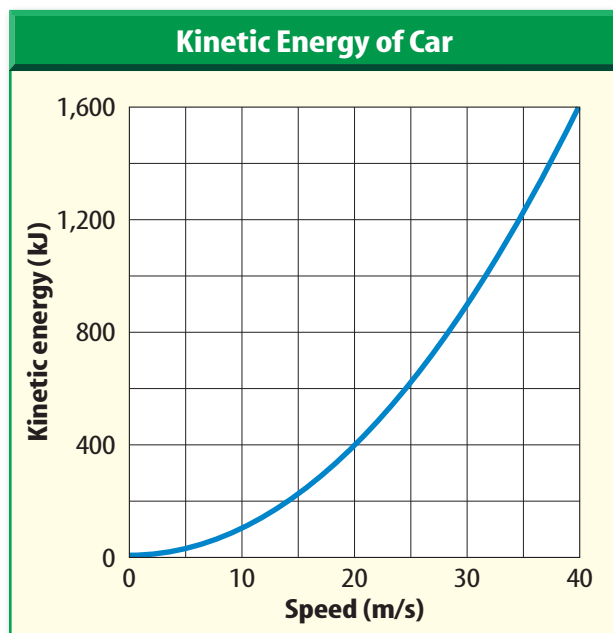


Use the table below to answer question 14.

Toy Cars Rolling Down Ramps			
Ramp Height (m)	Speed at Bottom (m/s)	GPE (J)	KE (J)
0.50	3.13		
0.75	3.83		
1.00	4.43		

- 14. Make and Use Tables** Three toy cars, each with a mass of 0.05 kg, roll down ramps with different heights. The height of each ramp and the speed of each car at the bottom of each ramp is given in the table. Copy and complete the table by calculating the GPE of each car at the top of the ramp and the KE for each car at the bottom of the ramp to two decimal places. How do the values of GPE and KE you calculate compare?

Use the graph below to answer questions 15–17.



- 15.** When the car's speed doubles from 20 m/s to 40 m/s, by how many times does the car's kinetic energy increase?

- 16.** Using the graph, estimate the car's kinetic energy at a speed of 50 m/s.
- 17.** If the car's kinetic energy at a speed of 20 m/s is 400 kJ, what is the car's kinetic energy at a speed of 10 m/s?

Thinking Critically

- 18. Describe** the energy changes that occur in a swing. Explain how energy is conserved as the swing slows down and stops.
- 19. Explain** why the law of conservation of energy must also include changes in mass.
- 20. Infer** why the tires of a car get hot when the car is driven.
- 21. Diagram** On a cold day you rub your hands together to make them warm. Diagram the energy transformations that occur, starting with the chemical potential energy stored in your muscles.

Applying Math

- 22. Calculate Kinetic Energy** What is the kinetic energy of a 0.06-kg tennis ball traveling at a speed of 150 m/s?
- 23. Calculate Potential Energy** A boulder with a mass of 2,500 kg rests on a ledge 200 m above the ground. What is the boulder's potential energy?
- 24. Calculate Mechanical Energy** What is the mechanical energy of a 500-kg roller-coaster car moving with a speed of 3 m/s at the top of hill that is 30 m high?
- 25. Calculate Speed** A boulder with a mass of 2,500 kg on a ledge 200 m above the ground falls. If the boulder's mechanical energy is conserved, what is the speed of the boulder just before it hits the ground?



Physical Science EOC Practice

Part 1 Multiple Choice

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

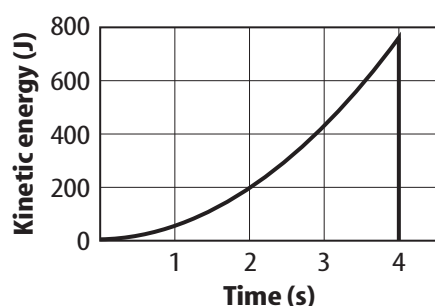
1. What is the potential energy of a 5.0-kg object located 2.0 m above the ground?

A. 2.5 J C. 98 J
B. 10 J D. 196 J

SCSh5e

Use the figure below to answer questions 2–4.

Kinetic Energy of Falling Rock



2. According to the graph, which of the following is the best estimate for the kinetic energy of the rock after it has fallen for 1 s?

A. 100 J C. 200 J
B. 50 J D. 0 J

SCSh3d

3. According to the graph, which of the following is the best estimate for the potential energy of the rock before it fell?

A. 400 J C. 200 J
B. 750 J D. 0 J

SCSh3d

4. If the rock has a mass of 1 kg, which of the following is the speed of the rock after it has fallen for 2 s?

A. 10 m/s C. 20 m/s
B. 100 m/s D. 200 m/s

SCSh5e

5. Which of the following describes the energy conversions in a car's engine?

A. chemical to thermal to mechanical
B. chemical to electrical to mechanical
C. thermal to mechanical to chemical
D. kinetic to potential to mechanical

SP57a

6. What is the difference in the gravitational potential energy of a 7.75 kg book that is 1.50 m above the ground and a 9.53 kg book that is 1.75 m above the ground?

A. 0.28 J C. 11.7 J
B. 5.1 J D. 49.5 J

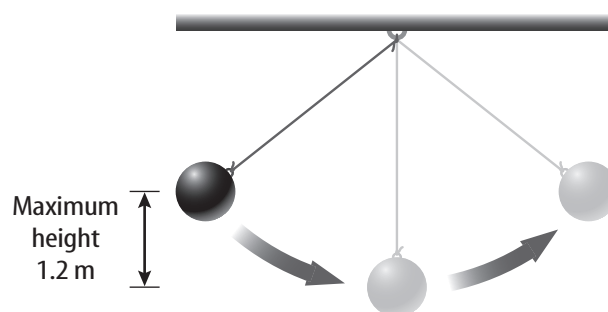
SCSh5e

7. A box with a mass of 14.8 kg sits on the floor. How high would you have to lift the box to for it to have a gravitational potential energy of 355 J?

A. 1.62 m C. 2.45 m
B. 2.40 m D. 4.90 m

SCSh5e

Use the figure below to answer questions 8 and 9.



8. At its highest point, the pendulum is 1.2 m above the ground and has a gravitational potential energy of 62 J. If the gravitational potential energy is 10 J at its lowest point, what is the pendulum's kinetic energy at this point?

A. 0 J C. 62 J
B. 31 J D. 52 J

SCSh5e

9. What is the mass of the pendulum bob?

A. 2.7 kg C. 6.3 kg
B. 5.3 kg D. 52 kg

SCSh5e

10. The SI unit of energy is the joule (J). Which of the following is an equivalent way of expressing this unit?

A. $\text{kg}\cdot\text{m}$ C. $\text{kg}\cdot\text{m}^2/\text{s}^2$
B. $\text{kg}\cdot\text{m}/\text{s}$ D. $\text{kg}\cdot\text{m}/\text{s}^2$

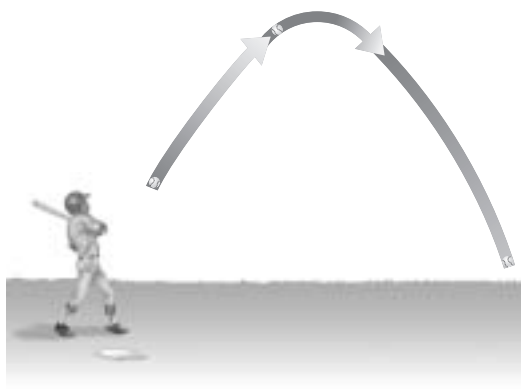
SCSh3c

Part 2 Short Response/Grid In

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

11. Explain why the law of conservation of energy also includes mass when applied to nuclear reactions.
12. A student walks to school at a speed of 1.2 m/s. If the student's mass is 53 kg, what is the student's kinetic energy?
13. A book sliding across a horizontal table slows down and comes to a stop. The book's kinetic energy was converted into what form of energy?
14. Electrical energy was converted into which forms of energy by a hair dryer?

Use the figure below to answer questions 15 and 16.

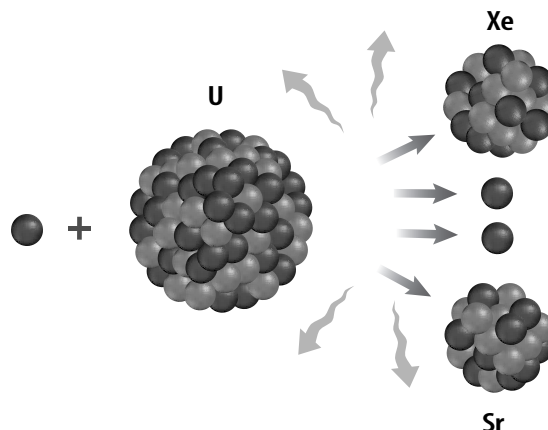


15. At what point on the ball's path is the ball's kinetic energy lowest but its gravitational potential energy highest?
16. How does the mechanical energy of the ball change from the moment just after the batter hits it to the moment just before it touches the ground?
17. Explain whether it is possible for an object at rest to have energy.
18. Find the speed of a 5.6-kg bowling ball that has a kinetic energy of 25.2 J.

Part 3 Open Ended

Record your answers on a sheet of paper.

Use the figure below to answer questions 19 and 20.



19. Describe the process shown in the figure above, and explain how it obeys the law of conservation of energy.
20. Describe how the total mass of the particles before the reaction occurs compares to the total mass of the particles produced by the reaction.
21. Is the mechanical energy of a liter of water at the top of a waterfall greater than, the same as, or less than the mechanical energy of a liter of water just before it reaches the bottom of the waterfall? Explain.
22. Name and describe some examples of how different forms of energy can be stored.
23. Describe a process in which energy travels through the environment and changes from one form to another.

Test-Taking Tip

Show All your Work For constructed response questions, show all your work and any calculations on your answer sheet.

Question 19 On your answer sheet, list the energy changes that occur during each for each step of the process that you can think of.