7.2 Energy and the Conservation of Energy

Energy appears in many forms, such as motion and heat. Energy can also travel in different ways, such as light and electricity. Without energy, nothing could ever change. In fact, the workings of the entire universe (including all of our technology) depend on energy flowing and changing back and forth from one form to another.

Defining energy

What is energy? **Energy** describes the ability of things to change or to cause change in other things. What types of changes are we talking about? Some examples are changes in temperature, speed, position, pressure, or any other physical variable. Energy can also cause changes in materials, such as when burning wood changes into ashes and smoke.

What has energy? The list below describes objects that have energy. Read through this list and notice how many different forms of energy exist.

- A gust of wind has energy because it can move objects in its path.
- A piece of wood burning in a fireplace has energy because it can produce heat and light.
- You have energy because you can change the motion of your body.
- Batteries have energy; they can be used in a radio to make sound.
- Gasoline has energy; it can be burned in an engine to move a car.
- A ball at the top of a hill has energy because it can roll down the hill and move objects in its path.

Measuring energy A **joule** (J) is the unit of measurement for energy. One joule is the energy needed to push with a force of 1 newton for a distance of 1 meter (Figure 7.11). So, 1 joule is equivalent to 1 newton multiplied by 1 meter (or 1 newton-meter). If you push a toy car forward with a force of 1 newton over a distance of 1 meter, you have applied 1 joule of energy to the car. One joule is a pretty small amount of energy. An ordinary 100-watt electric light bulb uses 100 joules of energy every second.

VOCABULARY

energy - a quantity that describes the ability of an object to change or cause changes.

joule - a unit of energy. One joule is enough energy to push with a force of 1 newton for a distance of 1 meter.

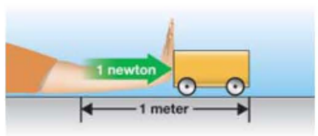


Figure 7.11: *Pushing an object with a force of 1 newton for a distance of 1 meter uses 1 joule of energy.*

Units Related to the Joule

1 joule = 1 newton-meter

1 newton = 1 kg-m/s^2

therefore...

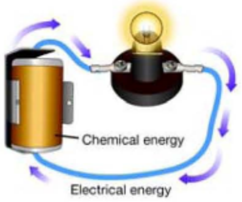
1 joule = 1 kg-m^2/s^2

Some forms of energy

Understanding energy One way to understand energy is to think of it as nature's money. Energy can be spent and saved in a number of different ways. It takes energy to "buy" changes such as going faster, moving higher, or getting hotter. These three changes *use* energy. The opposite changes, such as slowing down, falling, or cooling off, *release* energy. Just like a checkbook, nature keeps perfect track of energy. What you "spend" diminishes what you have left. You can only "buy" as much change as you have energy to "pay for."

Mechanical energy **Mechanical energy** is the energy possessed by an object due to its motion or its position. Turning windmill blades have mechanical energy.

Chemical energy **Chemical energy** is a form of energy stored in molecules. Batteries are really storage devices for chemical energy. The chemical energy in a battery changes to electrical energy when you connect wires and a light bulb to the battery. Your body also uses chemical energy when it converts food into energy so that you can walk or think. A car and many other types of machines use chemical energy when they burn fuel to operate.



Electrical energy Electrical energy comes from electric charge, which is one of the fundamental properties of all matter. The electrical energy we use in our homes is transformed from other forms of energy, such as the chemical energy released by burning oil and gas, or the mechanical energy released by falling water in a hydroelectric dam or power plant.

Pressure energy Pressure in gases and liquids is also a form of energy. An inflated bicycle tire has more energy than a flat tire. An inflated tire can hold up a bicycle (with you on it) against the force of gravity while a flat tire cannot.

VOCABULARY

mechanical energy - a form of energy that is related to motion or position.

chemical energy - a form of potential energy that is stored in molecules.

STUDY SKILLS

Keeping Track of Energy

In this section, you will learn about different forms of energy. Keep track of these in a table. List the name of each form of energy and write down any information you learn about it.

Energy	Notes
Mechanical energy	

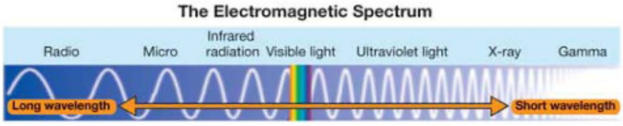
More forms of energy

Elastic energy Elastic energy is energy that is stored or released when an object changes shape (or deforms). For example, you use energy to stretch a rubber band. Some of the energy from your muscles is stored as elastic energy in the stretched (changed) shape of the rubber band. The energy is released again when the rubber band changes back to its original (unstretched) shape. Objects that are commonly used to store and release elastic energy include rubber bands, springs, and archery bows (Figure 7.12).

Nuclear energy and radiant energy Every second, about 5 million tons of mass is converted to energy through nuclear reactions in the core of the Sun. In the Sun, nuclear energy is transformed to heat that eventually escapes the Sun as radiant energy. **Nuclear energy** is a form of energy stored in the nuclei of atoms (particles of matter). You will read more about nuclear energy and nuclear reactions in Chapter 14. **Radiant energy** is energy that is carried by electromagnetic waves. Light is one form of radiant energy, and so are radio waves that carry music through the air.

The electromagnetic spectrum Light and radio waves are a traveling form of energy. In fact, they are only two of a whole family of energy waves called the electromagnetic spectrum. The electromagnetic spectrum includes infrared radiation (heat), visible light (what we see), and ultraviolet light. In other words, light energy and heat energy are included in the electromagnetic spectrum. You will recognize other components of the spectrum as well. You have listened to radio waves, might have cooked with microwaves, and maybe you have had an image made of a part of your body with X-rays.

The Electromagnetic Spectrum



VOCABULARY

nuclear energy - a form of energy that is stored in the nuclei of atoms.

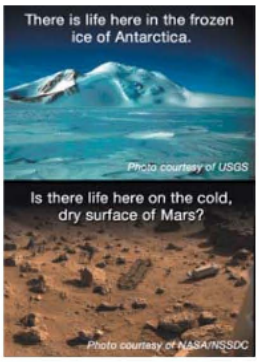
radiant energy - a form of energy that is represented by the electromagnetic spectrum.

Figure 7.12: *A stretched bowstring on a bent bow has elastic energy, so it is able to create change in itself and in the arrow.*

The Sun and gravity

The Sun and energy Living things and human technology derive virtually all of their energy from the Sun. Without the Sun's energy, Earth would be a cold, icy place. The Sun's energy not only warms the planet, it also drives the entire food chain (Figure 7.13). Plants store the energy as carbohydrates, such as sugar. Animals eat the plants to get energy. Other animals eat *those* animals for their energy. It all starts with the Sun.

Life on Mars and other planets A very important question in science today is whether there is life on other planets such as Mars. Mars is farther from the Sun than Earth. For this reason, Mars receives less energy from the Sun than does Earth. In fact, the average temperature on Mars is well below the freezing point of water. Can life exist on Mars? Recent research suggests that it might be possible. Scientists have found bacteria in the Antarctic ice living at a temperature colder than the average temperature of Mars.



Gravity and energy A falling rock gains speed as it falls. Energy must be supplied to increase speed. The falling water that turns a hydroelectric turbine must also have energy, otherwise no electrical energy could be produced. Where does this energy come from?

The answer has to do with Earth's gravity. If an object, or any matter, is lifted against gravity, energy is stored. This stored energy is transformed into energy of motion, such as the object falling back down. Many forms of human technology, including roller coasters, swings, water wheels, and hydroelectric power plants rely on gravity.

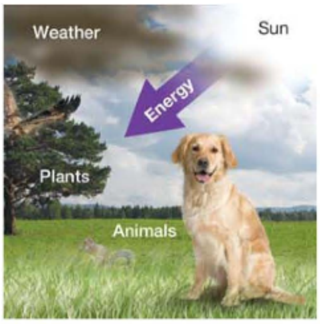


Figure 7.13: *The flow of energy from the Sun supports all living things on Earth.*

CHALLENGE

The planet Venus is closer to the Sun than Earth. Should this make Venus warmer or colder than Earth? Research your answer to see what scientists think Venus is like on its surface.

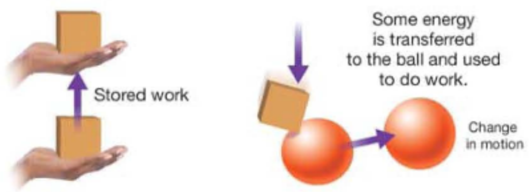
Energy and work

What *work* means in physics You learned in the previous section that *work* has a very specific meaning. *Work* is the transfer of energy that results from applying a force over a distance. Work is a product of the force applied times the distance traveled (work = force × distance). For example, if you push a block with a force of 1 newton for a distance of 1 meter, you do 1 joule of work. Both work and energy are measured in the same units (joules) because work is a form of energy.

Work and potential energy Doing work always means transferring energy. The energy might be transferred to the object to which force is applied, or it might go elsewhere. For example, you can increase the energy of a rubber band by exerting a force that stretches it. The work you do stretching the rubber band is stored as elastic potential energy by the rubber band. The rubber band can then use that stored energy to do work on a paper airplane, giving it energy (Figure 7.14).

Work is done on objects When thinking about work, you should always be clear about which force is doing the work on which object. Work is done on objects. If you lift a block 1 meter with a force of 1 newton, you have done 1 joule of work on the block.

Energy is needed to do work An object that has energy is able to do work; without energy, it is impossible to do work. In fact, energy can sometimes be thought of as *stored work*. As the block you lifted earlier falls, it has energy that can be used to do work. If the block hits a ball, it will do work on the ball and change the ball's motion. Some of the block's energy is transferred to the ball during the collision.



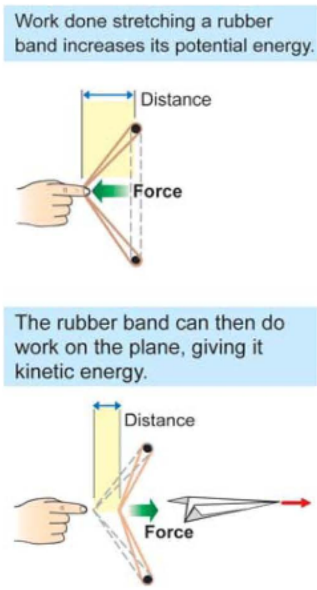


Figure 7.14: *You can do work to increase an object's energy. Then that energy can do work on another object, giving it energy.*

Potential energy

What is potential energy? **Potential energy** is energy due to position. The word *potential* means that something is capable of becoming active. Systems or objects with potential energy are able to exert forces (exchange energy) as they change to other arrangements. For example, a stretched spring has potential energy. If released, the spring will use this energy to move itself (and anything attached to it) back to its original length.

Gravitational potential energy A block suspended above a table has potential energy. If released, the force of gravity moves the block down to a position of lower energy. The term *gravitational potential energy* describes the energy of an elevated object. The term is often shortened to *potential energy* because the most common type of potential energy in physics problems is gravitational. Unless otherwise stated, you can assume *potential energy* means gravitational potential energy.

How to calculate potential energy How much potential energy does a raised block have? The block's potential energy is exactly the amount of work it can do as it goes down. Work is force multiplied by distance. The force is the weight (mg or mass × acceleration due to gravity) of the block in newtons. The distance the block can move down is its height (h) in meters. Multiplying the weight (mg) by the distance (h) gives you the block's potential energy (mgh) at any given height (Figure 7.15).

POTENTIAL ENERGY

$$E_p = mgh$$

Potential energy (J) — E_p; Mass (kg) — m; Acceleration due to gravity (9.8 m/s²) — g; Height (m) — h

VOCABULARY

potential energy - energy due to position.

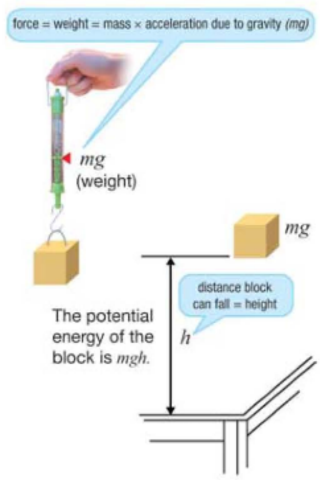


Figure 7.15: *The potential energy of the block is equal to the product of its mass, the strength of gravity, and the height from which the block can fall.*

Kinetic energy

Kinetic energy is energy of motion Objects that are moving also have the ability to cause change. Energy of motion is called **kinetic energy**. A moving billiard ball has kinetic energy because it can hit another ball and change its motion. Kinetic energy can easily be converted into potential energy. The kinetic energy of a basketball tossed upward converts into potential energy as the height increases.

Kinetic energy can do work The amount of kinetic energy an object has equals the amount of work the object can do by exerting force as it stops. Consider a moving skateboard and rider (Figure 7.16). Suppose it takes a force of 500 newtons applied over a distance of 10 meters to slow the skateboard to a stop (500 N × 10 m = 5,000 J). The kinetic energy of the skateboard and rider is 5,000 joules since that is the amount of work it takes to stop the skateboard.

Kinetic energy depends on mass and speed If you had started with twice the mass—say, two skateboarders—you would have to do twice as much work to stop them both. Kinetic energy increases with mass. If the skateboard and rider are moving faster, it also takes more work to bring them to a stop. This means kinetic energy also increases with speed. Kinetic energy is related to both an object's speed and its mass.

The formula for kinetic energy The kinetic energy of a moving object is equal to one-half its mass multiplied by the square of its speed. This formula comes from a combination of relationships, including Newton's second law, the distance equation for acceleration ($d = {}^1/_2at^2$), and the calculation of energy as the product of force and distance.

KINETIC ENERGY

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

Kinetic energy (J); Mass (kg); Speed (m/s)

VOCABULARY

kinetic energy - energy of motion.

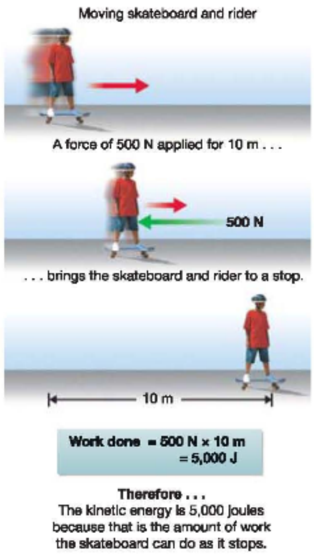


Figure 7.16: *The amount of kinetic energy the skateboard has is equal to the amount of work that must be done to stop the skateboard.*

Solving Problems: Potential and Kinetic Energy

A 2-kilogram rock is at the edge of a cliff 20 meters above a lake. The rock becomes loose and falls toward the water below. Calculate its potential and kinetic energy when it is at the top and when it is halfway down. Its speed is 14 m/s at the halfway point.

1. Looking for: You are asked for the potential and kinetic energy at two locations.

2. Given: You are given the mass in kilograms, the height at each location in meters, and the speed halfway down in m/s. You can assume the initial speed is 0 m/s because the rock starts from rest.

3. Relationships: $E_p = mgh$ and $E_k = \frac{1}{2}mv^2$

4. Solution: Potential energy at the top: $m = 2$ kg, $g = 9.8$ N/kg, and $h = 20$ m
$E_p = (2 \text{ kg})(9.8 \text{ N/kg})(20 \text{ m}) = 392 \text{ J}$

Potential energy halfway down: $m = 2$ kg, $g = 9.8$ N/kg, and $h = 10$ m
$E_p = (2 \text{ kg})(9.8 \text{ N/kg})(10 \text{ m}) = 196 \text{ J}$

Kinetic energy at the top: $m = 2$ kg and $v = 0$ m/s
$E_k = (1/2)(2 \text{ kg})(0^2) = 0 \text{ J}$

Kinetic energy halfway down: $m = 2$ kg and $v = 14$ m/s
$E_k = (1/2)(2 \text{ kg})(14 \text{ m/s})^2 = 196 \text{ J}$

Your turn...

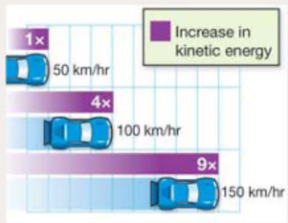
a. Calculate the potential energy of a 4-kilogram cat crouched 3 meters off the ground.

b. Calculate the kinetic energy of a 4-kilogram cat running at 5 m/s.

SCIENCE FACT

Kinetic Energy and Speed

Kinetic energy increases as the square of the speed. This means that if you go twice as fast, your energy increases by four times ($2^2 = 4$). If your speed is three times as fast, your energy is nine times bigger ($3^2 = 9$). A car moving at a speed of 100 km/h (62 mph) has four times the kinetic energy it had when going 50 km/h (31 mph). At a speed of 150 km/h (93 mph), it has nine times as much energy as it did at 50 km/h.
The stopping distance of a car is proportional to its kinetic energy. A car going twice as fast has four times the kinetic energy and needs four times the stopping distance. This is why driving at high speeds is so dangerous.



SOLVE FIRST LOOK LATER

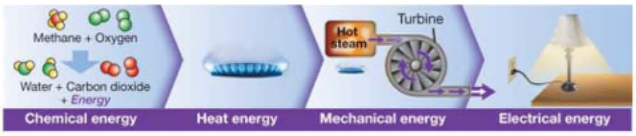
a. 117.6 J

b. 50 J

Transforming energy

An example of energy flow

Systems change as energy flows and changes from one part of the system to another. Parts of the system might speed up or slow down, get warmer or colder, or change in other measurable ways. Each change transfers energy or transforms energy from one form to another. An example of a flow of energy is illustrated below. This example involves transforming chemical energy into electrical energy. The chemical energy (a fuel) is a gas called methane. It is burned in a chemical reaction and heat energy is released. The heat energy makes hot steam. The steam turns a device called a turbine, making mechanical energy. Finally, the turbine turns an electric generator, producing electrical energy. You can obtain this electrical energy by "plugging in" to an electrical outlet.



From high to low energy

How can we predict how energy will flow? One thing we can always be sure of is that systems tend to move from higher to lower energy. For example, at the top of a roller coaster hill, the car has more potential energy (Figure 7.17). The potential energy is transformed to kinetic energy as the car rolls down the hill. Once it reaches the bottom, the car has less potential energy and is more stable.

Friction and the law of conservation of energy

At the bottom of a hill, a roller coaster car has more kinetic energy. Without friction, due to Newton's first law of motion, the car would roll on a straight path forever. However, on a straight path, the kinetic energy of the car eventually decreases due to friction slowing it down. Friction transforms energy of motion to energy of heat or to the wearing away of the material of the wheels. The energy converted to heat or wear is no longer available as potential energy or kinetic energy, but it was not destroyed.

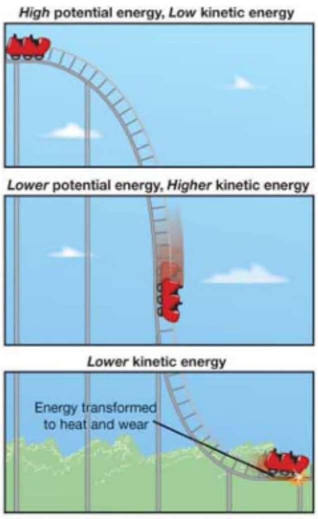


Figure 7.17: *This roller coaster car illustrates how systems go from high to low energy to become more stable. Potential energy decreases as the car rolls down the hill. Kinetic energy eventually decreases due to friction along the track and is transformed to heat and the wear of the wheels.*

The law of conservation of energy

An energy transformation What happens when you throw a ball straight up in the air (Figure 7.18)? The ball leaves your hand with kinetic energy it gained while your hand accelerated it from rest. As the ball goes higher, it gains potential energy. However, the ball slows down as it rises, so its kinetic energy decreases. The increase in potential energy is exactly equal to the decrease in kinetic energy. The kinetic energy converts into potential energy, and the ball's total energy stays the same.

Law of conservation of energy The idea that energy transforms from one form into another without a change in the total amount is called the **law of conservation of energy**. The law states that energy can never be created or destroyed, just transformed from one form into another. The law of conservation of energy is one of the most important laws in physics. It applies not only to kinetic and potential energy, but to all forms of energy.

Energy can never be created or destroyed, just transformed from one form into another.

Using energy conservation The law of conservation of energy explains how a ball's launch speed affects its motion. As the ball in Figure 7.17 moves upward, it slows down and loses kinetic energy. Eventually, it reaches a point where all the kinetic energy has been converted to potential energy. The ball has moved as high as it will go and its upward speed has been reduced to zero. If the ball had been launched with a greater speed, it would have started with more kinetic energy. It would have had to climb higher for all of the kinetic energy to be converted into potential energy. If the exact launch speed is given, the law of conservation of energy can be used to predict the height the ball reaches.

Energy converts from kinetic to potential The ball's energy on the way down is the opposite of what it was on the way up. As the ball falls, its speed increases and its height decreases. The potential energy decreases as it converts into kinetic energy. If gravity is the only force acting on the ball, it returns to your hand with exactly the same speed and kinetic energy it started with—except that now it moves in the opposite direction.

VOCABULARY

law of conservation of energy - energy can never be created or destroyed, only transformed into another form. The total amount of energy in the universe is constant.

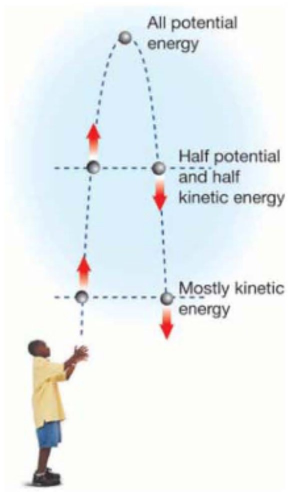


Figure 7.18: *When you throw a ball in the air, the energy transforms from kinetic to potential and then back to kinetic.*

"Using" and "conserving" energy in the everyday sense

"Conserving" energy Almost everyone has heard that it is good to "conserve energy" and not waste it. This is useful advice because energy from gasoline or electricity costs money and uses resources. But what does it mean to "use energy" in the everyday sense? If energy can never be created or destroyed, how can it be "used up"? Why do people worry about "running out" of energy?

"Using" energy When you "use" energy by turning on a light, you are really converting energy from one form (electricity) to other forms (light and heat). What gets "used up" is the amount of energy in the form of electricity. Electricity is a valuable form of energy because it is easy to move over long distances (through wires). In the physics sense, the energy is not used up—it is converted into other forms. The total amount of energy stays constant.

Power plants Electric power plants don't make electrical energy. Energy cannot be created. What power plants do is convert other forms of energy (chemical, solar, nuclear) into electrical energy. When someone asks you to turn out the lights to conserve energy, they are asking you to use less electrical energy. If people used less electrical energy, power plants would burn less oil, gas, or other fuels in "producing" the electrical energy they sell.

"Running out" of energy Many people are concerned about running out of energy. What they actually worry about is running out of certain forms of energy that are easy and economical to use, such as fossil fuels like oil and gas. It took millions of years to accumulate these fuels because they are derived from decaying, ancient plants that obtained their energy from the Sun when they were alive. Fossil fuels are a limited resource because it took a long time for plants to grow, decay, and become oil, coal and gas.

Transitioning to new resources When you use gas in a car, the chemical energy in the gasoline mostly becomes heat energy. It is impractical to put the energy back into the form of gasoline, so we say the energy has been "used up," even though the energy itself is still there, in a different form. Energy from flowing water, wind, or the Sun is not as limited. Many scientists hope our society will make a transition to these forms of energy over the next 100 years.

SCIENCE FACT

Switch to Fluorescent Bulbs

There are about 300,000,000 people in the United States. If an average house has 4 light bulbs per person, it adds up to 1,200,000,000 light bulbs. One kWh of electrical energy will light a bulb for 10 hours. Multiplying by 4 bulbs per person totals 120,000,000 kWh every hour just for light bulbs!

An average electric power plant puts out 1,000,000 kWh of electrical energy per hour. That means 120 power plants are burning up resources each hour just to run light bulbs! Regular (incandescent) light bulbs convert only 10 percent of electrical energy to light. Fluorescent bulbs make the same amount of light with one-quarter the electrical energy. If everyone switched from incandescent bulbs to fluorescent bulbs, we would save 75 percent of the electricity currently used for lighting!

Section 7.2 Review

1. Martha wakes up at 5:30 a.m. and eats a bowl of corn flakes. It's a nice day, so she decides to ride her bicycle to work, which is uphill from her house. It is still dark outside. Martha's bike has a small electric generator that runs from the front wheel. She flips on the generator so that her headlight comes on when she starts to pedal. She then rides her bike to work. Draw a diagram that shows the energy transformations that occur in this situation.

2. Imagine you are the teacher of a science class. A student brings in a newspaper article that claims the world will run out of energy by the year 2050 because all the oil will be pumped out of the planet. The student is confused because she has learned in your class that energy can never be created or destroyed. How would you explain to her what "running out of energy" means in the article?
3. Some, but not all, of the gasoline used by a car's engine is transformed into kinetic energy. Where else might some of the energy go in this system?
4. A 0.5-kg ball moving at a speed of 3 m/s rolls up a hill. How high does the ball roll before it stops?
5. Explain in your own words why energy is considered to be "nature's money." Give an example to support your explanation.

KEYWORDS

Energy Projects

Conduct Internet research on energy conservation. Use your favorite search engine and the following keywords to help you find information: *green communities*, *local energy conservation*, and *local electricity costs*. The United States Environmental Protection Agency is another good resource (www.epa.gov).

1. Research what is going on in your community regarding energy conservation. Write about a project designed to save energy that is being planned or is already implemented. How much energy has been or might be saved?
2. Every month your family pays an electric bill for energy you have used. Research the cost of electricity in your area. How much does it cost for 1 million joules? This is the amount of energy used by a single electric light bulb in three hours.