KEY CONCEPT

4.2 Energy is transferred when work is done.

BEFORE, you learned
- Work is the use of force to move an object
- Work can be calculated

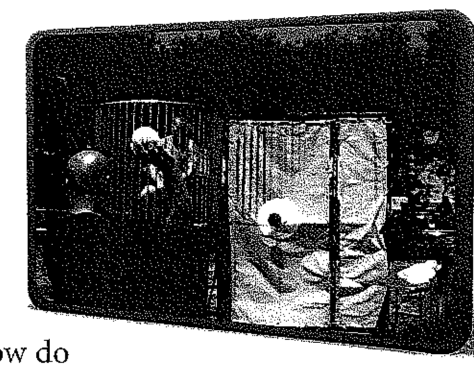
NOW, you will learn
- How work and energy are related
- How to calculate mechanical, kinetic, and potential energy
- What the conservation of energy means

VOCABULARY

potential energy p. 122
kinetic energy p. 122
mechanical energy p. 125
conservation of energy p. 126

THINK ABOUT

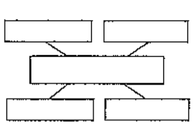
How is energy transferred?



School carnivals sometimes include dunk tanks. The goal is to hit a target with a ball, causing a person sitting over a tank of water to fall into the water. You do work on the ball as you throw with your arm. If your aim is good, the ball does work on the target. How do you transfer your energy to the ball?

Work transfers energy.

MAIN IDEA WEB
Remember to add boxes to your main idea web as you read.



When you change the position and speed of the ball in the carnival game, you transfer energy to the ball. Energy is the ability of a person or an object to do work or to cause a change. When you do work on an object, some of your energy is transferred to the object. You can think of work as the transfer of energy. In fact, both work and energy are measured in the same unit, the joule.

The man in the photograph above converts one form of energy into another form when he uses his muscles to toss the ball. You can think of the man and the ball as a system, or a group of objects that affect one another. Energy can be transferred from the man to the ball, but the total amount of energy in the system does not change.

CHECK YOUR READING How are work and energy related?

Work changes potential and kinetic energy.

READING TIP

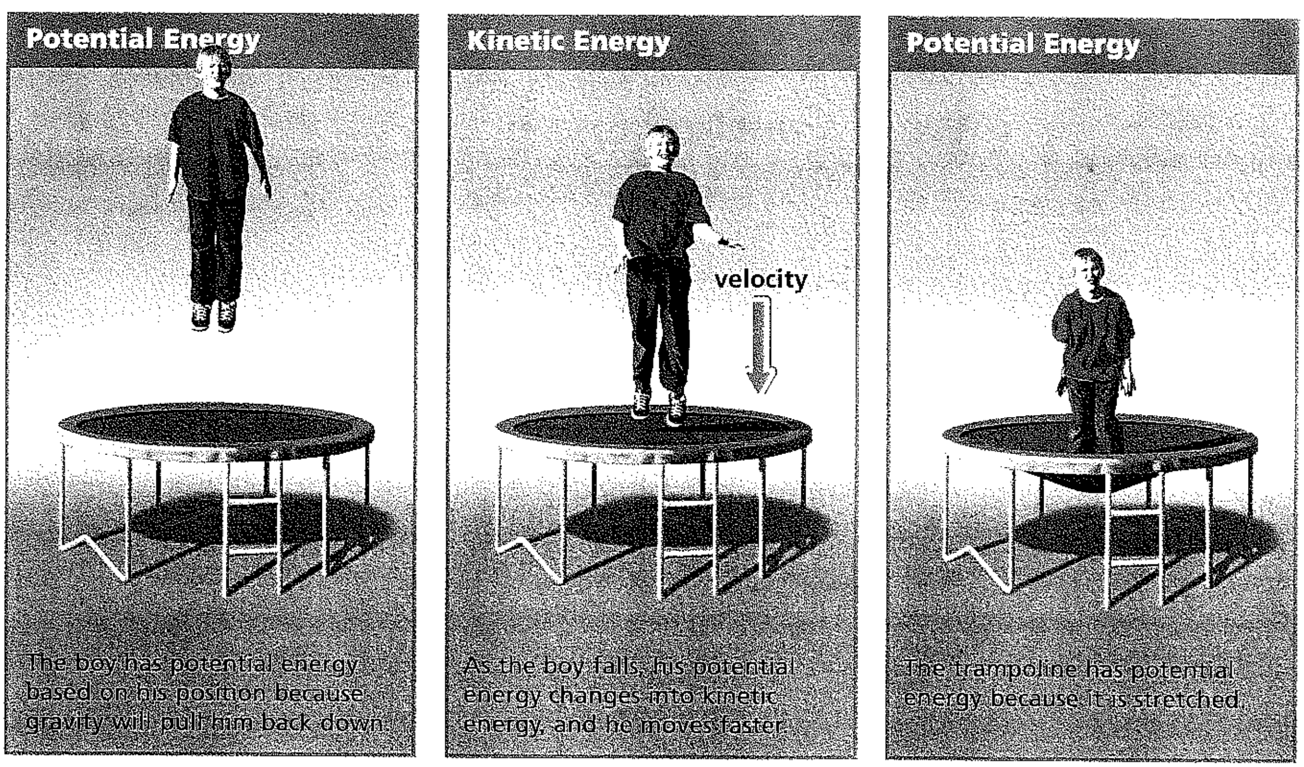
The word *potential* comes from the Latin word *potentia*, which means "power." The word *kinetic* comes from the Greek word *kinetos*, which means "moving."

Suppose you are holding a ball in the palm of your hand. Does the ball have any energy? You might say no because the ball is not moving. But not all energy involves movement. **Potential energy** is stored energy, or the energy an object has due to its position or shape. The ball's position in your hand gives the ball the potential to fall to the floor.

If the ball does fall, its potential energy is transformed into **kinetic energy** (kuh-NEHT-ihk), which is the energy of motion. A moving object has kinetic energy. It has the most kinetic energy at the point where it moves the fastest.

It is easy to tell that an object has kinetic energy because the object is moving. It is not so easy to tell how much and what kind of potential energy an object has, because an object can have potential energy for several reasons. For example, imagine that you are holding a spring. If you drop the spring, it will fall to the ground. The spring had potential energy due to its position. However, if the spring is compressed, it also has potential energy due to its shape—that is, how compressed or stretched it is. This type of potential energy, called elastic potential energy, depends on how compressed the spring is. Just as position gives the spring the potential to fall, compression gives the spring the potential to expand.

Potential and Kinetic Energy



The boy has potential energy based on his position because gravity will pull him back down.

As the boy falls, his potential energy changes into kinetic energy, and he moves faster.

The trampoline has potential energy because it is stretched.

Calculating Gravitational Potential Energy

Potential energy caused by gravity is called gravitational potential energy. Scientists must take gravitational potential energy into account when launching a spacecraft. Designers of roller coasters must make sure that roller-coaster cars have enough potential energy at the top of a hill to reach the top of the next hill. You can use the following formula to calculate the gravitational potential energy of an object:

Gravitational Potential Energy = mass · gravitational acceleration · height

$$GPE = mgh$$

Recall that g is the acceleration due to Earth's gravity. It is equal to 9.8 m/s^2 at Earth's surface.

The diver in the photograph below has given herself gravitational potential energy by climbing to the diving board. If you know her mass and the height of the board, you can calculate her potential energy.

Calculating Potential Energy

Sample Problem

What is the gravitational potential energy of a girl who has a mass of 40 kg and is standing on the edge of a diving board that is 5 m above the water?

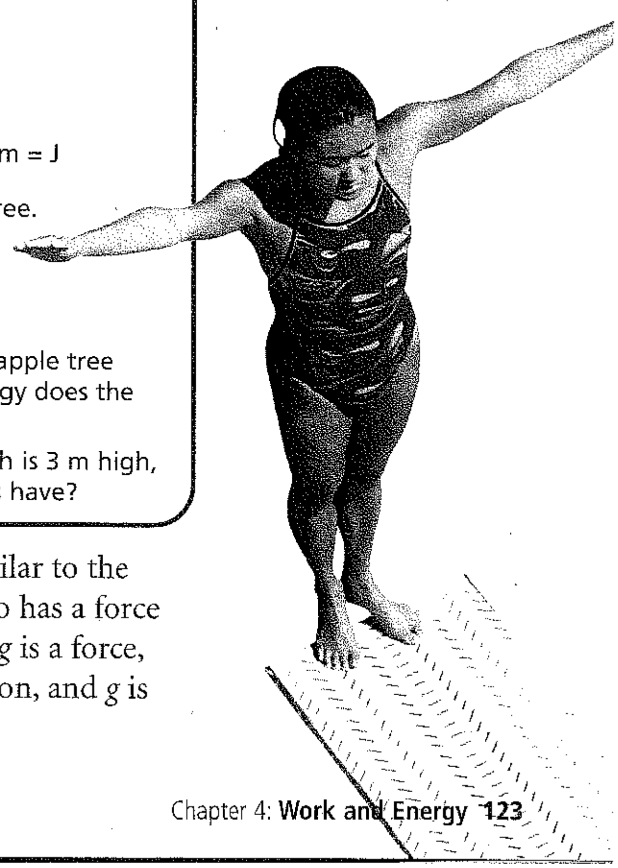
What do you know?	mass = 40 kg, gravitational acceleration = 9.8 m/s^2, height = 5 m
What do you want to find out?	Gravitational Potential Energy
Write the formula:	$GPE = mgh$
Substitute into the formula:	$GPE = 40 \text{ kg} \cdot 9.8 \text{ m/s}^2 \cdot 5 \text{ m}$
Calculate and simplify:	$GPE = 1960 \text{ kg m}^2/\text{s}^2$
Check that your units agree:	$\text{kg m}^2/\text{s}^2 = \text{kg} \cdot \text{m/s}^2 \cdot \text{m} = \text{N}\cdot\text{m} = \text{J}$
	Unit of energy is J. Units agree.
Answer:	$GPE = 1960 \text{ J}$

Practice the Math

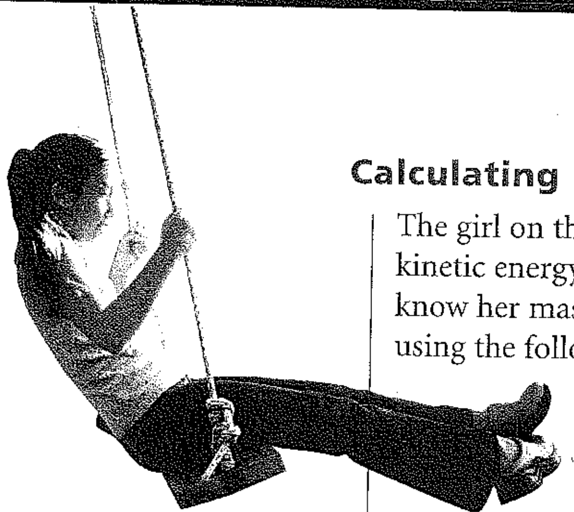
1. An apple with a mass of 0.1 kg is attached to a branch of an apple tree 4 m from the ground. How much gravitational potential energy does the apple have?
2. If you lift a 2 kg box of toys to the top shelf of a closet, which is 3 m high, how much gravitational potential energy will the box of toys have?

REMINDER

A newton (N) is a kg · m/s^2, and a joule (J) is a N·m.



The formula for gravitational potential energy is similar to the formula for work ($W = F \cdot d$). The formula for GPE also has a force (mg) multiplied by a distance (h). To understand why mg is a force, remember two things: force equals mass times acceleration, and g is the acceleration due to Earth's gravity.



Calculating Kinetic Energy

The girl on the swing at left has kinetic energy. To find out how much kinetic energy she has at the bottom of the swing's arc, you must know her mass and her velocity. Kinetic energy can be calculated using the following formula:

$$\text{Kinetic Energy} = \frac{\text{mass} \cdot \text{velocity}^2}{2}$$

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

Notice that velocity is squared while mass is not. Increasing the velocity of an object has a greater effect on the object's kinetic energy than increasing the mass of the object. If you double the mass of an object, you double its kinetic energy. Because velocity is squared, if you double the object's velocity, its kinetic energy is four times greater.

Calculating Kinetic Energy

Sample Problem

What is the kinetic energy of a girl who has a mass of 40 kg and a velocity of 3 m/s?

What do you know? mass = 40 kg, velocity = 3 m/s

What do you want to find out? Kinetic Energy

Write the formula: $KE = \frac{1}{2}mv^2$

Substitute into the formula: $KE = \frac{1}{2} \cdot 40 \text{ kg} \cdot (3 \text{ m/s})^2$

Calculate and simplify: $KE = \frac{1}{2} \cdot 40 \text{ kg} \cdot \frac{9 \text{ m}^2}{\text{s}^2}$

$= \frac{360 \text{ kg} \cdot \text{m}^2}{2 \text{ s}^2}$

$= 180 \text{ kg} \cdot \text{m}^2/\text{s}^2$

Check that your units agree: $\frac{\text{kg} \cdot \text{m}^2}{\text{s}^2} = \frac{\text{kg} \cdot \text{m}}{\text{s}^2} \cdot \text{m} = \text{N} \cdot \text{m} = \text{J}$

Unit of energy is J. Units agree.

Answer: $KE = 180$ J

Practice the Math

1. A grasshopper with a mass of 0.002 kg jumps up at a speed of 15 m/s. What is the kinetic energy of the grasshopper?
2. A truck with a mass of 6000 kg is traveling north on a highway at a speed of 17 m/s. A car with a mass of 2000 kg is traveling south on the same highway at a speed of 30 m/s. Which vehicle has more kinetic energy?

Calculating Mechanical Energy

Mechanical energy is the energy possessed by an object due to its motion or position—in other words, it is the object's combined potential energy and kinetic energy. A thrown baseball has mechanical energy as a result of both its motion (kinetic energy) and its position above the ground (gravitational potential energy). Any object that has mechanical energy can do work on another object.

Once you calculate an object's kinetic and potential energy, you can add the two values together to find the object's mechanical energy.

Mechanical Energy = Potential Energy + Kinetic Energy

$$ME = PE + KE$$

For example, a skateboarder has a potential energy of 200 joules due to his position at the top of a hill and a kinetic energy of 100 joules due to his motion. His total mechanical energy is 300 joules.

VOCABULARY
Use a vocabulary strategy to help you remember *mechanical energy.*

CHECK YOUR READING How is mechanical energy related to kinetic and potential energy?

INVESTIGATE Mechanical Energy

How does mechanical energy change?

SKILL FOCUS
Analyzing data

MATERIALS
- ball
- balance
- board
- books
- ruler
- tape
- stopwatch
- calculator

TIME
20 minutes

PROCEDURE

1. Find and record the mass of the ball.
2. Build a ramp with the board and books. Measure and record the height of the ramp. You will place the ball at the top of the ramp, so calculate the ball's potential energy at the top of the ramp using mass and height.
3. Mark a line on the floor with tape 30 cm from the bottom of the ramp.
4. Place the ball at the top of the ramp and release it without pushing. Time how long the ball takes to travel from the end of the ramp to the tape.
5. Calculate the ball's speed using the time you measured in step 4. Use this speed to calculate the ball's kinetic energy after it rolled down the ramp.

WHAT DO YOU THINK?

- At the top of the ramp, how much potential energy did the ball have? kinetic energy? mechanical energy?
- Compare the ball's mechanical energy at the top of the ramp with its mechanical energy at the bottom of the ramp. Are they the same? Why or why not?

CHALLENGE Other than gravity, what forces could have affected the movement of the ball?

The total amount of energy is constant.

VISUALIZATION
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Observe how potential and kinetic energy are transferred on an amusement park ride.

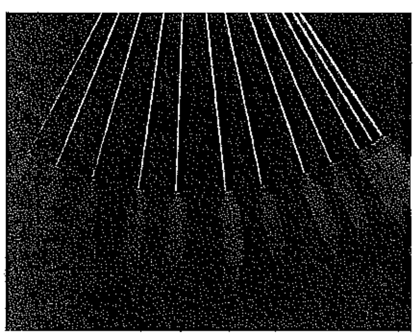
You know that energy is transferred when work is done. No matter how energy is transferred or transformed, all of the energy is still present somewhere in one form or another. This is known as the law of **conservation of energy.** As long as you account for all the different forms of energy involved in any process, you will find that the total amount of energy never changes.

Conserving Mechanical Energy

Look at the photograph of the in-line skater on page 127. As she rolls down the ramp, the amounts of kinetic energy and potential energy change. However, the total—or the mechanical energy—stays the same. In this example, energy lost to friction is ignored.

1. At the top of the ramp, the skater has potential energy because gravity can pull her downward. She has no velocity; therefore, she has no kinetic energy.
2. As the skater rolls down the ramp, her potential energy decreases because the elevation decreases. Her kinetic energy increases because her velocity increases. The potential energy lost as the skater gets closer to the ground is converted into kinetic energy. Halfway down the ramp, half of her potential energy has been converted to kinetic energy.
3. At the bottom of the ramp, all of the skater's energy is kinetic. Gravity cannot pull her down any farther, so she has no more gravitational potential energy. Her mechanical energy—the total of her potential and kinetic energy—stays the same throughout.

Losing Mechanical Energy



APPLY Energy must occasionally be added to a pendulum to keep it swinging. What keeps a grandfather clock's pendulum swinging regularly?

A pendulum is an object that is suspended from a fixed support so that it swings freely back and forth under the influence of gravity. As a pendulum swings, its potential energy is converted into kinetic energy and then back to potential energy in a continuous cycle. Ideally, the potential energy at the top of each swing would be the same as it was the previous time. However, the height of the pendulum's swing actually decreases slightly each time, until finally the pendulum stops altogether.

In most energy transformations, some of the energy is transformed into heat. In the case of the pendulum, there is friction between the string and the support, as well as air resistance from the air around the pendulum. The mechanical energy is used to do work against friction and air resistance. This process transforms the mechanical energy into heat. The mechanical energy has not been destroyed; it has simply changed form and been transferred from the pendulum.

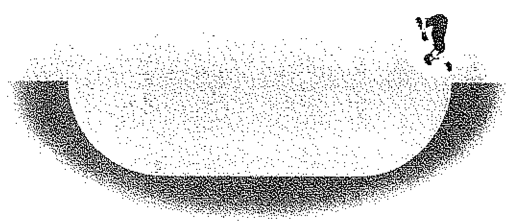
Conserving Mechanical Energy

The potential energy and kinetic energy in a system or process may vary, but the total energy remains unchanged.

① Top of Ramp

100% PE

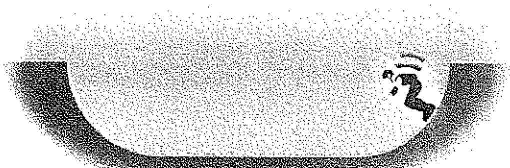
At the top of the ramp, the skater's mechanical energy is equal to her potential energy because she has no velocity.



② Halfway Down Ramp

50% PE | 50% KE

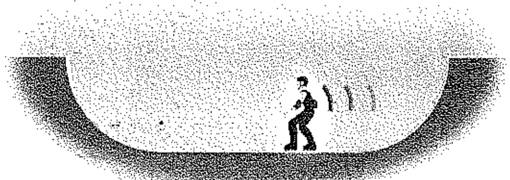
As the skater goes down the ramp, she loses height but gains speed. The potential energy she loses is equal to the kinetic energy she gains.

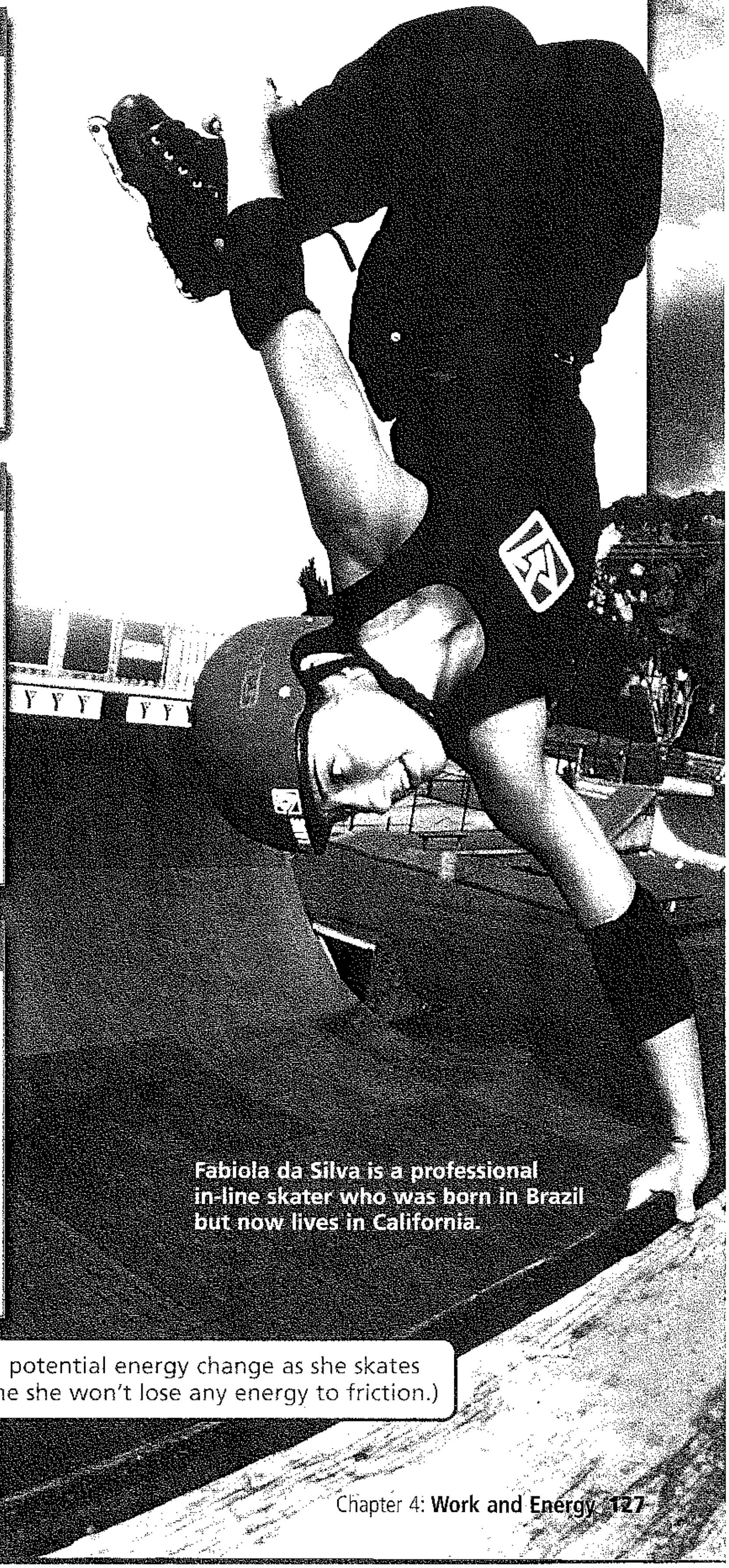


③ Bottom of Ramp

100% KE

As the skater speeds along the bottom of the ramp, all of the potential energy has changed to kinetic energy. Her mechanical energy remains unchanged.





Fabiola da Silva is a professional in-line skater who was born in Brazil but now lives in California.

READING VISUALS How do the skater's kinetic and potential energy change as she skates up and down the ramp? (Assume she won't lose any energy to friction.)