Name _____ Class _____ Date _____

CHAPTER 13 Work and Energy

SECTION 3

What Is Energy?

KEY IDEAS

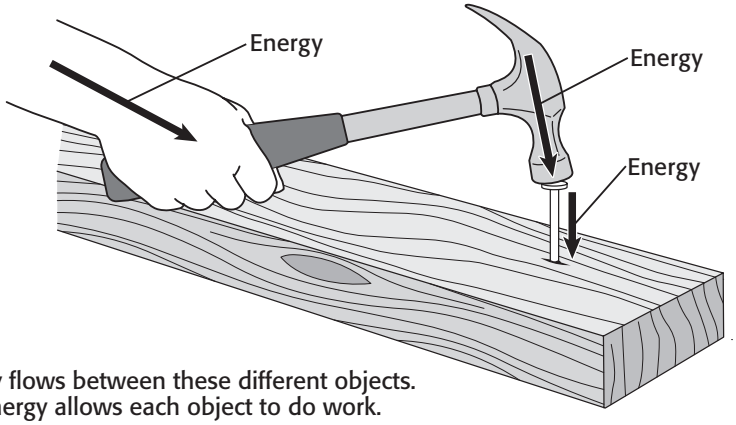
As you read this section, keep these questions in mind:

- How are energy and work related?
- Why is potential energy called energy of position?
- What is kinetic energy?
- What is mechanical energy?

What Is Energy?

The world around you is full of energy. A lightning bolt has electrical energy. Your body contains chemical energy from the food you eat. Obviously, energy exists in many forms, but what is energy? **Energy** is the ability to do work.

Whenever work is done, energy is transformed or transferred from one object to another object. For example, suppose you use a hammer to pound a nail into a piece of wood. You do work on the hammer. The hammer does work on the nail. The nail does work on the board. Each time one object does work on another, energy flows between the objects.



Energy flows between these different objects. The energy allows each object to do work.

READING TOOLBOX

Organize As you read this section, make a table listing the different forms of energy. Include definitions for each form of energy, an example of each form, and any equations used to calculate each form.

LOOKING CLOSER

1. Infer If your hand supplies the energy for the hammer to do work, where does the energy to move your hand come from?

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What Is Potential Energy?

An object at rest is not doing work, but it can have energy. How can that be? Such an object has potential energy. **Potential energy** is the energy an object has because of its position or shape. Potential energy is sometimes called *energy of position*, because it results from the relative positions of objects. ☑

READING CHECK

2. Identify Where does potential energy come from?

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TYPES OF POTENTIAL ENERGY

When you stretch a rubber band, you do work on it to change its shape. The energy you use to stretch the rubber is stored as potential energy until you release the rubber band. Any object that can be stretched or compressed has potential energy called *elastic potential energy.* Bungee cords, balls, and springs also have elastic potential energy.

An object that is above Earth's surface can fall to the ground and do work. Therefore, it has stored energy. This kind of stored energy is called *gravitational potential energy.* It is a result of the gravitational attraction between objects. Earth's gravitational force pulls on all objects near its surface. Therefore, all objects above Earth's surface have gravitational potential energy. ☑

READING CHECK

3. Explain Why do all objects above Earth's surface have gravitational potential energy?

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The car at the top of a hill on a roller coaster has gravitational potential energy. The car can do work when it moves down the hill.

Critical Thinking

4. Explain Why does gravitational potential energy depend on both mass and height?
(Hint: What two factors affect the strength of gravitational force?)

The gravitational potential energy of an object depends on both its mass and its height. If two objects are located at the same height, the more massive object has more gravitational potential energy. An object has more gravitational potential energy at a greater height than at a lower height.

CALCULATING POTENTIAL ENERGY

You can use the equation below to calculate the gravitational potential energy (PE) of an object:

$$gravitational\ PE = mass \times free\text{-}fall\ acceleration \times height$$

$$PE = mgh$$

Remember that an object's weight is equal to its mass (m) times gravitational free-fall acceleration (g). Therefore, gravitational potential energy is simply an object's weight multiplied by its height. The units of gravitational potential energy are the same as those of all types of energy: joules (J).

RELATIVE HEIGHT AND POTENTIAL ENERGY

In the potential energy equation, height usually means the distance of the object from the ground. However, in some cases a different height may be more useful.

For example, imagine an apple attached to the branch of a tree. Below the branch, there is a bird's nest. If the apple falls onto the nest, the apple will do work on the nest. The farther the apple falls before it hits the nest, the more work it will be able to do on the nest. To calculate the apple's gravitational potential energy relative to the nest, use the height of the apple above the nest.

Let's try an example. A 65 kg rock climber climbs 35 m up a cliff. What is the climber's gravitational potential energy? Remember that free-fall acceleration is equal to 9.8 m/s^2.

Step 1: List the given and unknown values.	**Given:** mass, $m = 65$ kg height, $h = 35$ m free-fall acceleration, $g = 9.8$ m/s^2	**Unknown:** gravitational potential energy, *PE*
Step 2: Write the equation.	$PE = mgh$	
Step 3: Insert the known values and solve for the unknown value.	$PE = (65\text{ kg}) \times (9.8\text{ m/s}^2) \times (35\text{ m})$ $PE = 22{,}000\text{ kg} \cdot \text{m}^2/\text{s}^2$ $PE = 2.2 \times 10^4$ J	

So, the climber's potential energy is 2.2×10^4 J.

What Is Kinetic Energy?

Think back to the apple hanging from a tree branch. When the apple is hanging, it has gravitational potential energy. What kind of energy does it have when it falls toward the ground? The energy an object has because it is moving is called **kinetic energy**.

The kinetic energy of an object depends on both the object's mass and its speed. A bowling ball can do more work than a tennis ball if both balls are moving at the same speed. This is because the bowling ball has more mass. On the other hand, two bowling balls rolling at different speeds have different kinetic energies. The ball rolling faster has more kinetic energy. ☑

Talk About It

Brainstorm In a small group, think of some examples of situations in which you shouldn't use the height of an object above the ground to calculate its gravitational potential energy.

Math Skills

5. Calculate A chef holds a 55 g egg above the floor. The egg has 0.65 J of gravitational potential energy. How far above the ground is the egg? Show your work.
(Hint: Rearrange the equation for gravitational potential energy to solve for height.)

READING CHECK

6. Identify What two factors affect an object's kinetic energy?

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KINETIC ENERGY AND SPEED

In fact, kinetic energy depends more on speed than on mass. To understand why this is, examine the equation for kinetic energy below:

$$kinetic\ energy = \frac{1}{2} \times mass \times speed\ squared$$

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

In the kinetic energy equation, speed is squared. Therefore, even a small change in speed causes a large change in kinetic energy. This is why car crashes at high speeds are much more dangerous than crashes at low speeds. A car has much more kinetic energy at high speeds, so it can do more work—damage—in a collision. The graph below shows the effect of speed on kinetic energy for a snowboarder.

Critical Thinking

7. Apply Concepts What will happen to the kinetic energy of an object if its speed doubles?

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Graphing Skills

8. Read a Graph What is the snowboarder's kinetic energy when her speed is 5 m/s?

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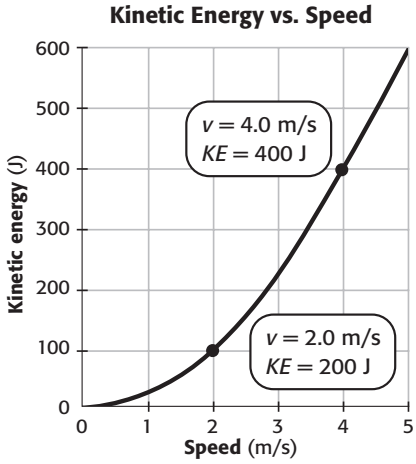

A small increase in speed produces a larger increase in kinetic energy. This is because kinetic energy is proportional to speed squared.

KINETIC ENERGY OF ATOMS AND MOLECULES

Atoms and molecules are always moving, so they have kinetic energy. The faster the particles in a substance are moving, the higher its temperature. This is because temperature is a measure of the average kinetic energy of the particles in a substance. For example, the molecules in a glass of water have more kinetic energy than molecules in an ice cube. ☑

READING CHECK

9. Describe What happens to an object's temperature if the kinetic energy of its particles decreases?

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Another quantity that describes the kinetic energy of particles is thermal energy. Thermal energy is the total kinetic energy of all the particles in an object. Unlike temperature, thermal energy depends on the mass of an object, as well as how fast its particles are moving.

CALCULATING KINETIC ENERGY

You can use the kinetic energy equation to calculate the energy of a moving object. For example, if a 44 kg cheetah is running at a speed of 31 m/s, what is its kinetic energy?

Step 1: List the given and unknown values.	**Given:** mass, $m = 44$ kg speed, $v = 31$ m/s	**Unknown:** kinetic energy, *KE*
Step 2: Write the equation.	$KE = \frac{1}{2} mv^2$	
Step 3: Insert the known values and solve for the unknown value.	$KE = \frac{1}{2}$ (44 kg) $\times$ (31 m/s^2) $KE = 21{,}000$ kg • m^2/s^2 $KE = 2.1 \times 10^4$ J	

So, the cheetah has 2.1×10^4 J of kinetic energy.

Math Skills

10. Calculate A bowling ball travels at 2.0 m/s. It has 16 J of kinetic energy. What is the mass of the bowling ball in kilograms? Show your work. (Hint: Rearrange the kinetic energy equation to solve for mass.)

What Is Mechanical Energy?

How would you describe the energy of an apple falling from a tree? Because the apple is moving, it has kinetic energy. Until the apple hits the ground, the apple also has potential energy. As the apple falls, its potential energy changes into kinetic energy.

Both gravitational potential energy and kinetic energy are forms of mechanical energy. **Mechanical energy** is the amount of work something can do because of its kinetic and potential energies. The mechanical energy of an object is equal to the sum of its gravitational potential energy and its kinetic energy: ☑

mechanical energy = kinetic energy + potential energy

An object's mechanical energy can be all potential energy, all kinetic energy, or some of both. An object's mechanical energy remains the same as long as no energy is added it. If an object's potential energy increases because its position has changed, its kinetic energy must decrease. If its potential energy decreases, its kinetic energy must increase.

READING CHECK

11. Define What is mechanical energy?

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What Is Nonmechanical Energy?

There are forms of energy other than mechanical energy. For example, your body uses energy from the food you eat. The energy in food comes from the sun. The appliances in your home run on electrical energy. Many of these forms of *nonmechanical energy* come from the interactions between atoms and molecules. ☑

READING CHECK

12. Identify Where do many forms of nonmechanical energy come from?

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CHEMICAL ENERGY

Chemical energy is a kind of potential energy. In a chemical reaction, bonds between the atoms of a substance break apart. When the atoms form new bonds, different substances are formed. The breaking and making of bonds involves energy. *Chemical energy* is energy stored in the bonds of substances. The amount of chemical energy in a substance depends on the arrangement of atoms in the substance.

LOOKING CLOSER

13. Describe Where does the energy in an unburned match come from?

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Matches contain chemical energy in the form of chemical compounds. When the matches burn, the chemical energy is converted to heat and light energy.

CHEMICAL ENERGY IN LIVING THINGS

All living things require energy. They use energy to grow, reproduce, move, and defend themselves. The energy they use comes from food.

Plants, algae, and certain bacteria can make their own food. These organisms use energy from the sun to change carbon dioxide and water into sugar and oxygen. This process is called *photosynthesis*.

READING CHECK

14. Identify What kind of energy do plants convert sunlight into during photosynthesis?

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Sugars and other foods, like all chemical compounds, contain chemical energy. Living things obtain the energy they need from food. They break the bonds in the chemicals they eat and store the energy in other compounds. ☑

NUCLEAR ENERGY

Remember that the strong nuclear force holds protons and neutrons together in the nuclei of atoms. As a result of this force, atomic nuclei contain potential energy called *nuclear energy*. Some kinds of reactions can release this energy. For example, within the sun and most other stars, atomic nuclei *fuse*, or combine. This *nuclear fusion* releases energy. People use *nuclear fission*, or the breaking apart of nuclei, to produce electricity. ☑

READING CHECK

15. Identify Name two kinds of nuclear energy.

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ELECTRICAL ENERGY

Most of the appliances that we use every day are powered by electricity. Electricity is a form of *electrical energy*, which comes from the movements of charged particles.

Electrical energy is similar to gravitational potential energy. Charged particles move from areas of high electric potential to areas of low electric potential. This is similar to what happens when an object falls to the ground. When the charged particles move, they transmit energy.

LIGHT ENERGY

Think about a hot, sunny day at the beach such as the one in the figure below. Is the sand hotter under the shade of the umbrella or where sunlight is shining directly on the sand? You might guess, correctly, that the sand in the direct sunlight is hotter. The reason is that sunlight carries energy. The energy from the sun heats the Earth.

Electromagnetic waves carry energy from the sun to Earth. Most objects absorb some of these waves. The energy in the waves is then converted to heat energy.

LOOKING CLOSER

16. Explain Why is the sand cooler under the umbrella than outside the umbrella?

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Light energy travels from the sun to the Earth across empty space in the form of *electromagnetic waves*. Electromagnetic waves can travel through empty space.

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Section 3 Review

SECTION VOCABULARY

energy the capacity to do work **kinetic energy** the energy of an object that is due to the object's motion	**mechanical energy** the amount of work an object can do because of the object's kinetic and potential energies **potential energy** the energy that an object has because of the position, shape, or condition of the object

1. Explain A boy on a bicycle is resting at the top of a hill. Then, he rides his bicycle down the hill. Describe how the boy's potential and kinetic energy differ at the top, middle, and bottom of the hill.

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2. Describe Fill in the table. Decide what form or forms of energy apply to each situation and whether each form is mechanical or nonmechanical energy.

Situation	Form(s) of Energy	Mechanical or nonmechanical?
Frisbee moving through the air	kinetic and potential energy	
Cup of hot soup		nonmechanical
Sunlight	light energy	
Boulder sitting at the top of a hill		
A lit lightbulb	electrical energy and light energy	

3. Apply Concepts Why are water storage tanks usually built on towers or hilltops?

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4. Calculate What is the potential energy of a 35 kg child sitting at the top of a slide that is 3.5 m above the ground? What is her kinetic energy if she moves down the slide at a speed of 5.0 m/s? Show your work.