كلية العلوم

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SECTION 1

Energy

KEY TERMS

- energy
- physical change
- chemical change
- evaporation
- endothermic
- exothermic
- law of conservation of energy
- heat
- kinetic energy
- temperature
- specific heat

OBJECTIVES

1. **Explain** that physical and chemical changes in matter involve transfers of energy.
2. **Apply** the law of conservation of energy to analyze changes in matter.
3. **Distinguish** between heat and temperature.
4. **Convert** between the Celsius and Kelvin temperature scales.

Energy and Change

If you ask 10 people what comes to mind when they hear the word *energy*, you will probably get 10 different responses. Some people think of energy in terms of exercising or playing sports. Others may picture energy in terms of a fuel or a certain food.

If you ask 10 scientists what comes to mind when they hear the word *energy*, you may also get 10 different responses. A geologist may think of energy in terms of a volcanic eruption. A biologist may visualize cells using oxygen and sugar in reactions to obtain the energy they need. A chemist may think of a reaction in a lab, such as the one shown in **Figure 1.**

The word *energy* represents a broad concept. One definition of **energy** is the capacity to do some kind of work, such as moving an object, forming a new compound, or generating light. No matter how energy is defined, it is always involved when there is a change in matter.

energy
the capacity to do work

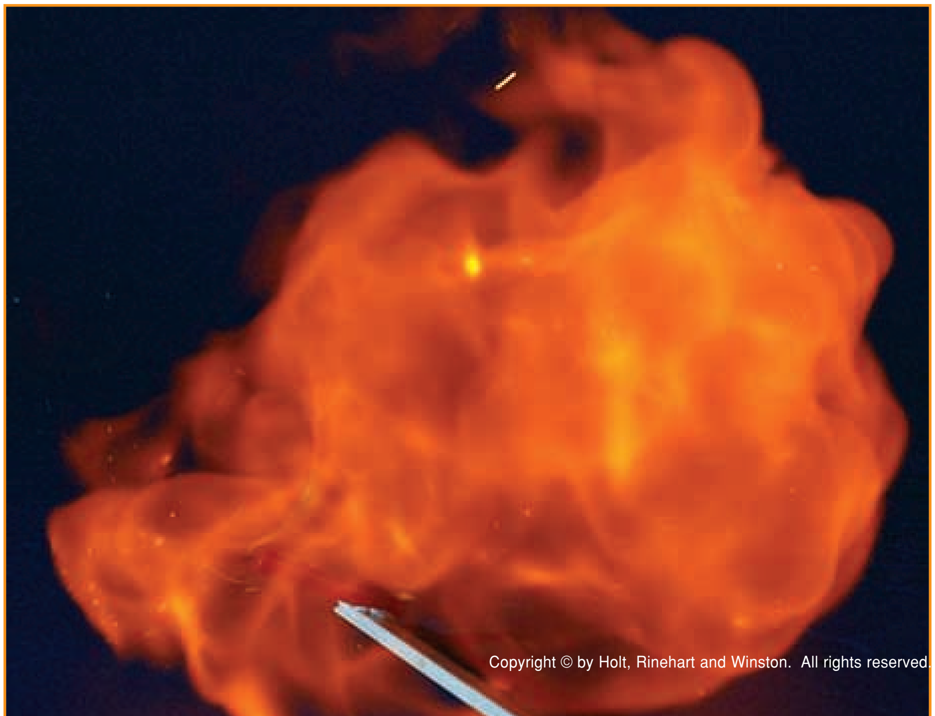


Figure 1
Energy is released in the explosive reaction that occurs between hydrogen and oxygen to form water.

Changes in Matter Can Be Physical or Chemical

Ice melting and water boiling are examples of **physical changes.** A physical change affects only the physical properties of matter. For example, when ice melts and turns into liquid water, you still have the same substance represented by the formula H_2O. When water boils and turns into a vapor, the vapor is still H_2O. Notice that in these examples the chemical nature of the substance does not change; only the physical state of the substance changes to a solid, liquid, or gas.

physical change
a change of matter from one form to another without a change in chemical properties

In contrast, the reaction of hydrogen and oxygen to produce water is an example of a **chemical change.** A chemical change occurs whenever a new substance is made. In other words, a chemical reaction has taken place. You know water is different from hydrogen and oxygen because water has different properties. For example, the boiling points of hydrogen and oxygen at atmospheric pressure are –252.8°C and –182.962°C, respectively. The boiling point of water at atmospheric pressure is 100°C. Hydrogen and oxygen are also much more reactive than water.

chemical change
a change that occurs when one or more substances change into entirely new substances with different properties

Every Change in Matter Involves a Change in Energy

All physical and chemical changes involve a change in energy. Sometimes energy must be supplied for the change in matter to occur. For example, consider a block of ice, such as the one shown in **Figure 2.** As long as the ice remains cold enough, the particles in the solid ice stay in place.

However, if the ice gets warm, the particles will begin to move and vibrate more and more. For the ice to melt, energy must be supplied so that the particles can move past one another. If more energy is supplied and the boiling point of water is reached, the particles of the liquid will leave the liquid's surface through **evaporation** and form a gas. These physical changes require an input of energy. Many chemical changes also require an input of energy.

evaporation
the change of a substance from a liquid to a gas

Sometimes energy is released when a change in matter occurs. For example, energy is released when a vapor turns into a liquid or when a liquid turns into a solid. Some chemical changes also release energy. The explosion that occurs when hydrogen and oxygen react to form water is a release of energy.

Figure 2
Energy is involved when a physical change, such as the melting of ice, happens.

Endothermic and Exothermic Processes

endothermic

describes a process in which heat is absorbed from the environment

Any change in matter in which energy is absorbed is known as an **endothermic** process. The melting of ice and the boiling of water are two examples of physical changes that are endothermic processes.

Some chemical changes are also endothermic processes. **Figure 3** shows a chemical reaction that occurs when barium hydroxide and ammonium nitrate are mixed. Notice in **Figure 3** that these two solids form a liquid, slushlike product. Also, notice the ice crystals that form on the surface of the beaker. As barium hydroxide and ammonium nitrate react, energy is absorbed from the beaker's surroundings. As a result, the beaker feels colder because the reaction absorbs energy as heat from your hand. Water vapor in the air freezes on the surface of the beaker, providing evidence that the reaction is endothermic.

exothermic

describes a process in which a system releases heat into the environment

Any change in matter in which energy is released is an **exothermic** process. The freezing of water and the condensation of water vapor are two examples of physical changes that are exothermic processes.

Recall that when hydrogen and oxygen gases are mixed to form water, an explosive reaction occurs. The vessel in which the reaction takes place becomes warmer after the reaction, giving evidence that energy has been released.

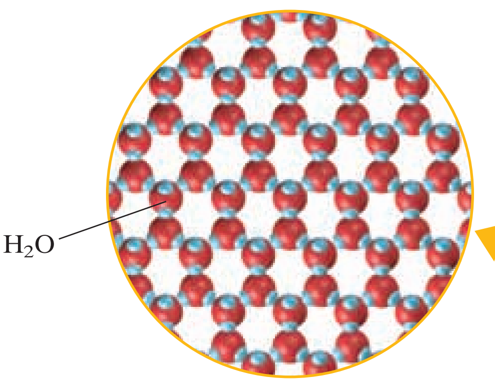
law of conservation of energy

the law that states that energy cannot be created or destroyed but can be changed from one form to another

Endothermic processes, in which energy is absorbed, may make it seem as if energy is being destroyed. Similarly, exothermic processes, in which energy is released, may make it seem as if energy is being created. However, the **law of conservation of energy** states that during any physical or chemical change, the total quantity of energy remains constant. In other words, energy cannot be destroyed or created.

Accounting for all the different types of energy present before and after a physical or chemical change is a difficult process. But measurements of energy during both physical and chemical changes have shown that when energy seems to be destroyed or created, energy is actually being transferred. The difference between exothermic and endothermic processes is whether energy is absorbed or released by the substances involved.

Figure 3
The reaction between barium hydroxide and ammonium nitrate absorbs energy and causes ice crystals to form on the beaker.



Conservation of Energy in a Chemical Reaction

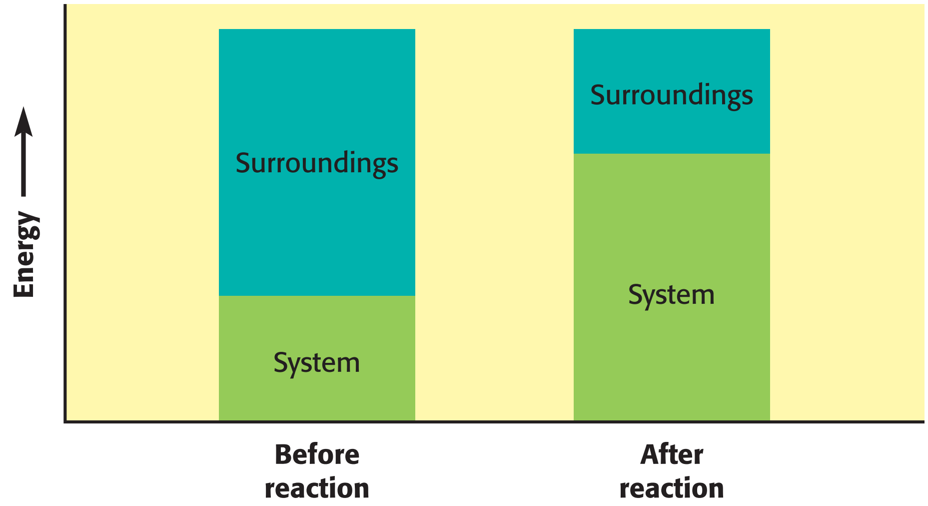


Figure 4
Notice that the energy of the reactants and products increases, while the energy of the surroundings decreases. However, the total energy does not change.

Energy Is Often Transferred

Figure 4 shows the energy changes that take place when barium hydroxide and ammonium nitrate react. To keep track of energy changes, chemists use the terms *system* and *surroundings*. A system consists of all the components that are being studied at any given time. In **Figure 4,** the system consists of the mixture inside the beaker. The surroundings include everything outside the system. In **Figure 4,** the surroundings consist of everything else including the air both inside and outside the beaker and the beaker itself. Keep in mind that the air is made of various gases.

Energy is often transferred back and forth between a system and its surroundings. An exothermic process involves a transfer of energy from a system to its surroundings. An endothermic process involves a transfer of energy from the surroundings to the system. However, in every case, the total energy of the systems and their surroundings remains the same, as shown in **Figure 4.**

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Energy Can Be Transferred in Different Forms

Energy exists in different forms, including chemical, mechanical, light, heat, electrical, and sound. The transfer of energy between a system and its surroundings can involve any one of these forms of energy. Consider the process of *photosynthesis*. Light energy is transferred from the sun to green plants. Chlorophyll inside the plant's cells (the system) absorbs energy—the light energy from the sun (the surroundings). This light energy is converted to chemical energy when the plant synthesizes chemical nutrients that serve as the basis for sustaining all life on Earth.

Next, consider what happens when you activate a light stick. Chemicals inside the stick react to release energy in the form of light. This light energy is transferred from the system inside the light stick to the surroundings, generating the light that you see. A variety of animals depend on chemical reactions that generate light, including fish, worms, and fireflies.

Heat

heat
the energy transferred between objects that are at different temperatures; energy is always transferred from higher-temperature objects to lower-temperature objects until thermal equilibrium is reached

Heat is the energy transferred between objects that are at different temperatures. This energy is always transferred from a warmer object to a cooler object. For example, consider what happens when ice cubes are placed in water. Energy is transferred from the liquid water to the solid ice. The transfer of energy as heat during this physical change will continue until all the ice cubes have melted. But on a warm day, we know that the ice cubes will not release energy that causes the water to boil, because energy cannot be transferred from the cooler objects to the warmer one. Energy is also transferred as heat during chemical changes. In fact, the most common transfers of energy in chemistry are those that involve heat.

Energy Can Be Released As Heat

The worst industrial disaster in U.S. history occurred in April 1947. A cargo ship named the *Grandcamp* had been loaded with fertilizer in Texas City, a Texas port city of 50 000 people. The fertilizer consisted of tons of a compound called *ammonium nitrate.* Soon after the last bags of fertilizer had been loaded, a small fire occurred, and smoke was noticed coming from the ship's cargo hold. About an hour later, the ship exploded.

The explosion was heard 240 km away. An anchor from the ship flew through the air and created a 3 m wide hole in the ground where it landed. Every building in the city was either destroyed or damaged. The catastrophe on the *Grandcamp* was caused by an exothermic chemical reaction that released a tremendous amount of energy as heat.

Figure 5
Billowing black smoke filled the sky over Texas City in the aftermath of the *Grandcamp* explosion, shown in this aerial photograph.

All of this energy that was released came from the energy that was stored within the ammonium nitrate. Energy can be stored within a chemical substance as chemical energy. When the ammonium nitrate ignited, an exothermic chemical reaction took place and released energy as heat. In addition, the ammonium nitrate explosion generated **kinetic energy,** as shown by the anchor that flew through the air.

kinetic energy
the energy of an object that is due to the object's motion

Energy Can Be Absorbed As Heat

In an endothermic reaction, energy is absorbed by the chemicals that are reacting. If you have ever baked a cake or a loaf of bread, you have seen an example of such a reaction. Recipes for both products require either baking soda or baking powder. Both baking powder and baking soda contain a chemical that causes dough to rise when heated in an oven.

The chemical found in both baking powder and baking soda is sodium bicarbonate. Energy from the oven is absorbed by the sodium bicarbonate. The sodium bicarbonate breaks down into three different chemical substances, sodium carbonate, water vapor, and carbon dioxide gas, in the following endothermic reaction:

$$2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$$

The carbon dioxide gas causes the batter to rise while baking, as you can see in **Figure 6.**

Figure 6
Baking a cake or bread is an example of an endothermic reaction, in which energy is absorbed as heat.

Heat Is Different from Temperature

You have learned that energy can be transferred as heat because of a temperature difference. So, the transfer of energy as heat can be measured by calculating changes in temperature. Temperature indicates how hot or cold something is. **Temperature** is actually a measurement of the average kinetic energy of the random motion of particles in a substance.

temperature
a measure of how hot (or cold) something is; specifically, a measure of the average kinetic energy of the particles in an object

For example, imagine that you are heating water on a stove to make tea. The water molecules have kinetic energy as they move freely in the liquid. Energy transferred as heat from the stove causes these water molecules to move faster. The more rapidly the water molecules move, the greater their average kinetic energy. As the average kinetic energy of the water molecules increases, the temperature of the water increases. Think of heat as the energy that is transferred from the stove to the water because of a difference in the temperatures of the stove and the water. The temperature change of the water is a measure of the energy transferred as heat.

Temperature Is Expressed Using Different Scales

Thermometers are usually marked with the Fahrenheit or Celsius temperature scales. However, the Fahrenheit scale is not used in chemistry. Recall that the SI unit for temperature is the *Kelvin,* K. The zero point on the Celsius scale is designated as the freezing point of water. The zero point on the Kelvin scale is designated as *absolute zero,* the temperature at which the minimum average kinetic energies of all particles occur.

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In chemistry, you will have to use both the Celsius and Kelvin scales. At times, you will have to convert temperature values between these two scales. Conversion between these two scales simply requires an adjustment to account for their different zero points.

$$t(°\text{C}) = T(\text{K}) - 273.15\ \text{K} \qquad T(\text{K}) = t(°\text{C}) + 273.15°\text{C}$$

The symbols t and T represent temperatures in degrees Celsius and in kelvins, respectively. Also, notice that a temperature change is the same in kelvins and in Celsius degrees.

Transfer of Heat May Not Affect the Temperature

The transfer of energy as heat does not always result in a change of temperature. For example, consider what happens when energy is transferred to a solid such as ice. Imagine that you have a mixture of ice cubes and water in a sealed, insulated container. A thermometer is inserted into the container to measure temperature changes as energy is added to the ice-water mixture.

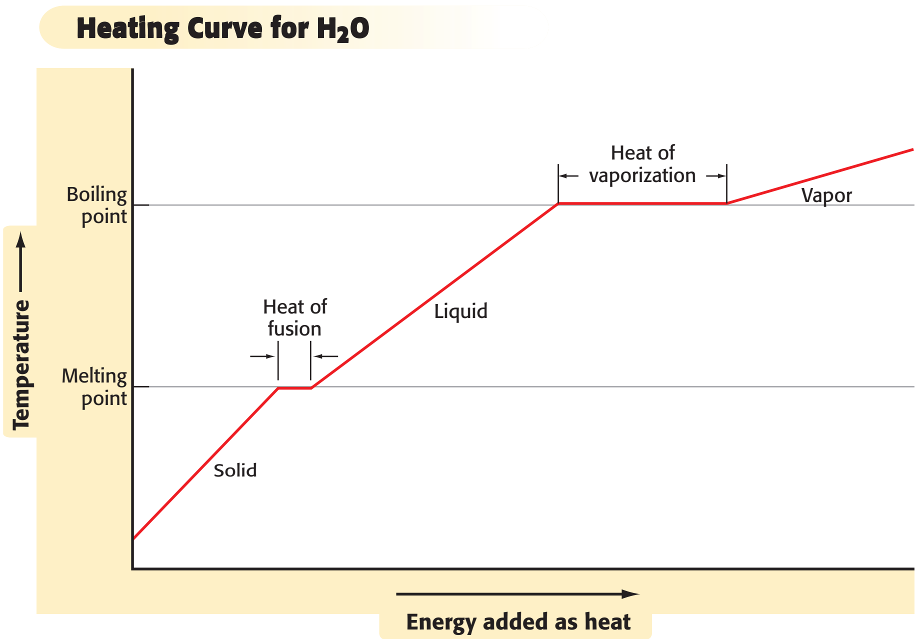
As energy is transferred as heat to the ice-water mixture, the ice cubes will start to melt. However, the temperature of the mixture remains at 0°C. Even though energy is continuously being transferred as heat, the temperature of the ice-water mixture does not increase.

Once all the ice has melted, the temperature of the water will start to increase. When the temperature reaches 100°C, the water will begin to boil. As the water turns into a gas, the temperature remains at 100°C, even though energy is still being transferred to the system as heat. Once all the water has vaporized, the temperature will again start to rise.

Notice that the temperature remains constant during the physical changes that occur as ice melts and water vaporizes. What happens to the energy being transferred as heat if the energy does not cause an increase in temperature? The energy that is transferred as heat is actually being used to move molecules past one another or away from one another. This energy causes the molecules in the solid ice to move more freely so that they form a liquid. This energy also causes the water molecules to move farther apart so that they form a gas.

Figure 7 shows the temperature changes that occur as energy is transferred as heat to change a solid into a liquid and then into a gas. Notice that the temperature increases only when the substance is in the solid, liquid, or gaseous states. The temperature does not increase when the solid is changing to a liquid or when the liquid is changing to a gas.

Figure 7
This graph illustrates how temperature is affected as energy is transferred to ice as heat. Notice that much more energy must be transferred as heat to vaporize water than to melt ice.



Transfer of Heat Affects Substances Differently

Have you ever wondered why a heavy iron pot gets hot fast but the water in the pot takes a long time to warm up? If you transfer the same quantity of heat to similar masses of different substances, they do not show the same increase in temperature. This relationship between energy transferred as heat to a substance and the substance's temperature change is called the **specific heat.**

specific heat

the quantity of heat required to raise a unit mass of homogeneous material 1 K or 1°C in a specified way given constant pressure and volume

The specific heat of a substance is the quantity of energy as heat that must be transferred to raise the temperature of 1 g of a substance 1 K. The SI unit for energy is the *joule* (J). Specific heat is expressed in joules per gram kelvin (J/g•K).

Metals tend to have low specific heats, which indicates that relatively little energy must be transferred as heat to raise their temperatures. In contrast, water has an extremely high specific heat. In fact, it is the highest of most common substances.

During a hot summer day, water can absorb a large quantity of energy from the hot air and the sun and can cool the air without a large increase in the water's temperature. During the night, the water continues to absorb energy from the air. This energy that is removed from the air causes the temperature of the air to drop quickly, while the water's temperature changes very little. This behavior is explained by the fact that air has a low specific heat and water has a high specific heat.

1 Section Review

UNDERSTANDING KEY IDEAS

1. What is energy?

2. State the law of conservation of energy.

3. How does heat differ from temperature?

4. What is a system?

5. Explain how an endothermic process differs from an exothermic process.

6. What two temperature scales are used in chemistry?

PRACTICE PROBLEMS

7. Convert the following Celsius temperatures to Kelvin temperatures.

a. 100°C **c.** 0°C

b. 785°C **d.** –37°C

8. Convert the following Kelvin temperatures to Celsius temperatures.

a. 273 K **c.** 0 K

b. 1200 K **d.** 100 K

CRITICAL THINKING

9. Is breaking an egg an example of a physical or chemical change? Explain your answer.

10. Is cooking an egg an example of a physical or chemical change? Explain your answer.

11. What happens in terms of the transfer of energy as heat when you hold a snowball in your hands?

12. Why is it impossible to have a temperature value below 0 K?

13. If energy is transferred to a substance as heat, will the temperature of the substance always increase? Explain why or why not.