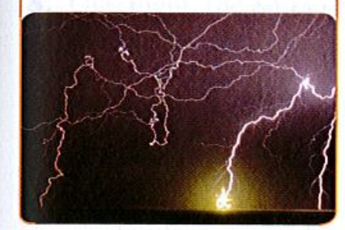
LESSON 1

Fired Up!
Energy Changes

ENVIRONMENTAL CONNECTION

Lightning strikes sometimes cause wildfires. It's probable that humans first discovered fire through lightning strikes.



Think About It

Fire is central to our lives. The most familiar fires are wood, oil, and gas fires. When these substances are ignited, brilliant flames leap into the air and there is intense heat. The energy from fire is used to warm homes, to cook food, and to move cars. For millennia, fire has been a vital energy source for humankind.

What reactions are sources of heat?

To answer this question, you will explore

1. Energy
2. Exothermic Processes

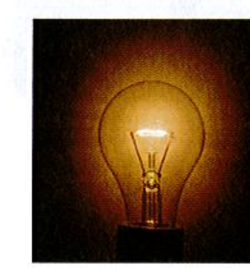
Exploring the Topic

1 Energy

The universe consists of matter and energy. As discussed in Unit 1: Alchemy, matter is made up of atoms of different elements. So, what is energy?

Because energy is not matter, it is not a substance. Energy does not have mass and it does not take up space. Energy is difficult to describe and define. Take a moment to examine how the word *energy* is used in the following sentences. What do these situations have in common?

- A plant needs energy from the Sun to grow.
- An athlete eats a snack bar for energy to continue running.
- A campfire provides energy to heat water.
- Energy from a waterfall makes the waterwheel rotate.
- Electrical energy causes the filament in the light bulb to glow.
- Pressure from steam provides the energy to move a locomotive.



You may notice that all of the statements are about energy causing something to happen to matter. Matter moves, falls, glows, melts, breaks apart, or burns. In each case, matter changes in some way and energy causes the change to happen. So, one definition of energy is that it is about change. **Energy** is a measure of the ability to cause change to occur. Even though you cannot see energy or hold it in your hand, you can measure amounts of energy transferred to a substance or from a substance.

② Exothermic Processes

The chemical reactions listed here all release energy. This is evident in the flames, the sparks, the light you see, the sounds you hear, and the heat you feel when you observe these reactions. A reaction that creates products that are hotter than the reactants is called **exothermic.** Take a moment to examine these exothermic reactions.

Heat, Light, Flames

The first two equations involve molecular covalent compounds. They react with oxygen, O_2. The products include carbon dioxide and water. Heat, light, and flames accompany these reactions.

$$\text{Methane: } CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(g)$$

$$\text{Propanol: } 2C_3H_8O(l) + 9O_2(g) \longrightarrow 6CO_2(g) + 8H_2O(g)$$

Heat, Light, Sparks

The second set of equations involves elemental substances. Elemental metals and many nonmetals also react with oxygen to produce heat and light. There are no flames associated with these reactions, but sometimes sparks are emitted.

$$\text{Phosphorus: } P_4(s) + 5O_2(g) \longrightarrow 2P_2O_5(s)$$

$$\text{Iron: } 4Fe(s) + 3O_2(g) \longrightarrow 2Fe_2O_3(s)$$

In all of these exothermic reactions, the reactants change into products that are very hot. These hot products cool down over time as they transfer heat to the surroundings. Exothermic changes are associated with big changes to matter.

HISTORY CONNECTION

The Great Fire of London occurred in 1666. The fire lasted for four days, destroying 13,200 homes. Historians credit this fire with eradicating the rat population and helping to end the Great Bubonic Plague that had killed almost 20 percent of the city's populace.

Fire

When you observe fire, matter is changing drastically. As a result of a fire, an entire forest can be reduced to smoke and ashes. During this change, the trees and brush are converted to carbon dioxide and water, which spread out in the atmosphere in gaseous form. Some ash and charred fuel remain after a fire. These are the result of reactants that did not react completely.

Flames are generally what distinguish fires from other exothermic reactions. Flames consist mainly of hot gases. The glowing yellow color of a wood fire is caused by small particles of carbon carried into the air by the gaseous products of this exothermic reaction.

BIG IDEA Changes in matter are accompanied by changes in energy.

Key Terms

energy
exothermic

Lesson Summary

What reactions are sources of heat?

Energy is not a substance, so it does not have mass and it does not take up space. However, any change in matter is accompanied by a change in energy. Many chemical reactions are exothermic, which means they result in products that are hotter than the reactants. Fire is an important example of an exothermic reaction that transfers energy in the form of light and heat. In a fire, reactants combine with oxygen to form carbon dioxide and water. The energy associated with fires has many uses such as heating your home, cooking your food, and moving cars.

EXERCISES

Reading Questions

1. In your own words, define the word *energy.*

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LITERATURE CONNECTION

Many myths and legends have attempted to explain the origins of fire. According to Greek mythology, Prometheus stole fire from the gods on Mount Olympus and brought it to humankind. He was punished for it by Zeus.

LESSON

2 Not So Hot

Exothermic and Endothermic

Think About It

You just received a bad bruise on your leg playing sports. The bruise is swelling and is quite painful. Your coach pulls out a disposable cold pack from the first-aid kit. A quick twist of the package activates it, and the temperature of the cold pack suddenly decreases. It feels nice and cold on your injury. What is the source of this cold sensation?

In what direction is heat transferred during a chemical process?

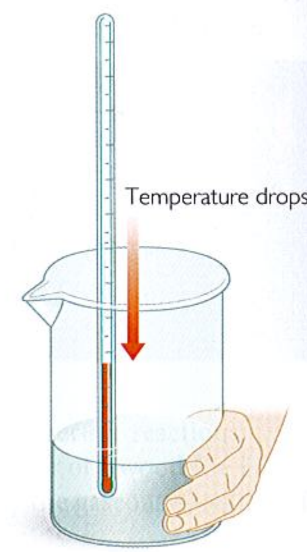
To answer this question, you will explore

1. Heat
2. Exothermic and Endothermic Processes
3. Kinetic Energy

Exploring the Topic

1 Heat

Therapeutic hot and cold packs are fairly easy to make. In one type of hot pack, solid calcium chloride, $CaCl_2$, is separated from water in two different pouches. When the pack is twisted, the pouches break open and the solid $CaCl_2$ dissolves in the water, releasing heat. The temperature of the solution increases and the bag feels hot. In contrast, one type of cold pack has solid ammonium nitrate, NH_4NO_3, separated from water in two different pouches. When you twist the pouch and the NH_4NO_3 dissolves in the water, the temperature of the solution decreases and the bag feels cold. If you perform these two reactions in beakers, you can measure the temperature changes with a thermometer.

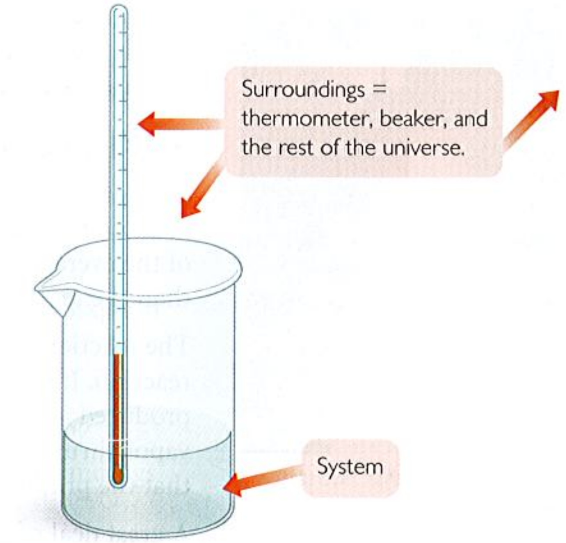


When you dissolve ammonium nitrate in water, the temperature decreases. The beaker feels cold.

What the thermometer records and your hand experiences is energy transferred into or out of the products of the chemical change. This process of energy transfer is called heat. **Heat** is a transfer of energy between two objects due to temperature differences. Heat always transfers from a higher temperature to a lower temperature. So, for instance, when the beaker feels cold to your hand, it is because heat transfers from your hand to the beaker.

System and Surroundings

In order to communicate clearly about heat transfer, it is necessary to specify where the heat is transferring to or from. The matter that you are focusing on is referred to as the **system.** Once you have defined the system, everything else is referred to as the **surroundings,** or environment. If the solution of ammonium nitrate and water is the system, then the beaker, the thermometer, the air around the beaker, your hand, and everything else in the universe constitutes the surroundings.



Heat transfers between a system and its surroundings.

BIG IDEA Heat is a transfer of energy due to temperature differences.

2 Exothermic and Endothermic Processes

Chemists categorize chemical changes according to the direction of heat transfer. As you learned in the previous lesson, when heat is transferred out of the system to the surroundings, the process is exothermic. When heat is transferred from the surroundings to the system, the process is **endothermic.** (In Latin, *exo* means outside and *endo* means inside.) Exothermic processes are experienced as warm by an observer. Endothermic processes are experienced as cold by an observer.

Some examples of exothermic and endothermic changes are listed below. The word *heat* is included in the chemical equation to highlight the direction of heat transfer.

Exothermic Processes

Burning methane gas

$$CH_4(g) + O_2(g) \longrightarrow CO_2(g) + H_2O(g) + \text{heat}$$

Dissolving calcium chloride in water

$$CaCl_2(s) \longrightarrow Ca^{2+}(aq) + 2Cl^-(aq) + \text{heat}$$

Neutralization of sodium hydroxide with hydrochloric acid

$$NaOH(aq) + HCl(aq) \longrightarrow H_2O(l) + NaCl(aq) + \text{heat}$$

Endothermic Processes

Dissolving ammonium nitrate in water

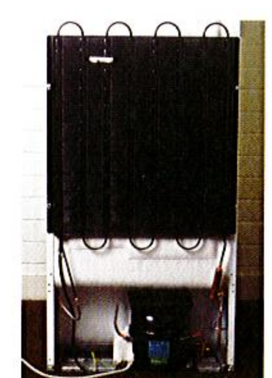
$$NH_4NO_3(s) + \text{heat} \longrightarrow NH_4^+(aq) + NO_3^-(aq)$$

Decomposition of mercury oxide

$$2HgO(l) + \text{heat} \longrightarrow 2Hg(l) + O_2(g)$$

CONSUMER CONNECTION

Most household refrigerators contain a liquid called a *refrigerant* that circulates in a series of coiled tubes. As it evaporates, the refrigerant absorbs heat from inside of the refrigerator. The refrigerant is then condensed back into a liquid in tubes located in back of the refrigerator, releasing heat, and the process starts all over again.



The shuttle launches due to the reaction of H_2 and O_2. The water vapor produced expands rapidly to thrust the shuttle upward.

Notice that heat transfer is not limited to chemical reactions. The process of dissolving is also exothermic or endothermic depending on the substance. This is because energy is involved every time atoms are rearranged.

❸ Kinetic Energy

Changes in temperature due to a chemical reaction are associated with changes in motion. **Kinetic energy** is the energy of motion, and temperature is a reflection of the average kinetic energy of a sample. If the products of a reaction are hotter than the reactants, they must be moving faster.

The reaction between H_2 and O_2 to produce H_2O is an extremely exothermic reaction. It is the reaction used to launch the space shuttle. The water molecules produced in the reaction are so hot and they expand so rapidly that the water vapor thrusts the space shuttle up into the air. The photo here provides evidence that the product molecules are moving with explosive speed.

A great deal of the heat energy of this reaction is converted to kinetic energy in the form of rapidly moving water molecules. While the water molecules push the space shuttle up, they transfer some of their kinetic energy to the space shuttle. They also transfer some of their energy to the surroundings as heat. With less kinetic energy, the water molecules gradually become cooler and move more slowly.

*The effectiveness to create new compounds is increased when heated

Key Terms

heat
system
surroundings
endothermic
kinetic energy

Lesson Summary

In what direction is heat transferred during a chemical process?

Heat is a transfer of energy between two objects due to temperature differences. Heat transfer accompanies all chemical changes. The heat is transferred either into the system or out of the system. Exothermic reactions are chemical processes that result in the transfer of heat *from* the products of the reaction (the system) *to* the surroundings. These reactions feel hot to the observer. Endothermic reactions are chemical processes that result in the transfer of heat *from* the surroundings *to* the products of the reaction. These reactions feel cold to the observer. Because temperature is directly related to the motion of molecules, hotter products mean faster moving molecules. Colder products mean slower moving molecules.

EXERCISES

Reading Questions

1. In your own words, define exothermic and endothermic chemical changes.

Reason and Apply

3. Methane, $CH_4(g)$, reacts with oxygen, $O_2(g)$, to produce carbon dioxide, $CO_2(g)$, and water, $H_2O(g)$. You observe flames.
   a. How does the average kinetic energy of the reactants differ from the average kinetic energy of the products?
   b. Describe what you would expect to see if you had a molecular view of the products and reactants.

4. You mix solid copper (II) sulfate, $CuSO_4(s)$, with a small amount of water, $H_2O(l)$ in a beaker. Hydrated copper (II) sulfate, $CuSO_4{\cdot}5H_2O(s)$ is produced. A thermometer inside the beaker indicates that the temperature has increased from 19 °C to 48 °C.

$$CuSO_4(s) + 5H_2O(l) \longrightarrow CuSO_4{\cdot}5H_2O(s)$$

   a. List all the substances that are part of the system.
   b. List at least four things that are part of the surroundings.
   c. Which is at a lower temperature: $CuSO_4(s)$ or $CuSO_4{\cdot}5H_2O(s)$? Explain your thinking.
   d. What will you feel if you touch the beaker?
   e. Is the process endothermic or exothermic? Explain your thinking.
   f. What evidence do you have that heat is transferred *to* the surroundings *from* the products of the reaction?

5. You mix solid hydrated barium hydroxide, $Ba(OH)_2{\cdot}8H_2O(s)$, and solid ammonium nitrate, $2NH_4NO_3(s)$, in a beaker. The reaction is shown here. A small pool of water in contact with the outside of the beaker freezes.

$$Ba(OH)_2{\cdot}8H_2O(s) + 2NH_4NO_3(s) \longrightarrow 2NH_3(g) + 10H_2O(l) + Ba(NO_3)_2(aq)$$

   a. List all the substances that are part of the system.
   b. List at least four objects that are part of the surroundings.
   c. Which is at a lower temperature: $NH_4NO_3(s)$ or $Ba(NO_3)_2(aq)$? Explain your thinking.
   d. What will you feel if you touch the beaker?
   e. Is the reaction endothermic or exothermic? Explain your thinking.
   f. What evidence do you have that heat is transferred *from* the surroundings *to* the products of the reaction?

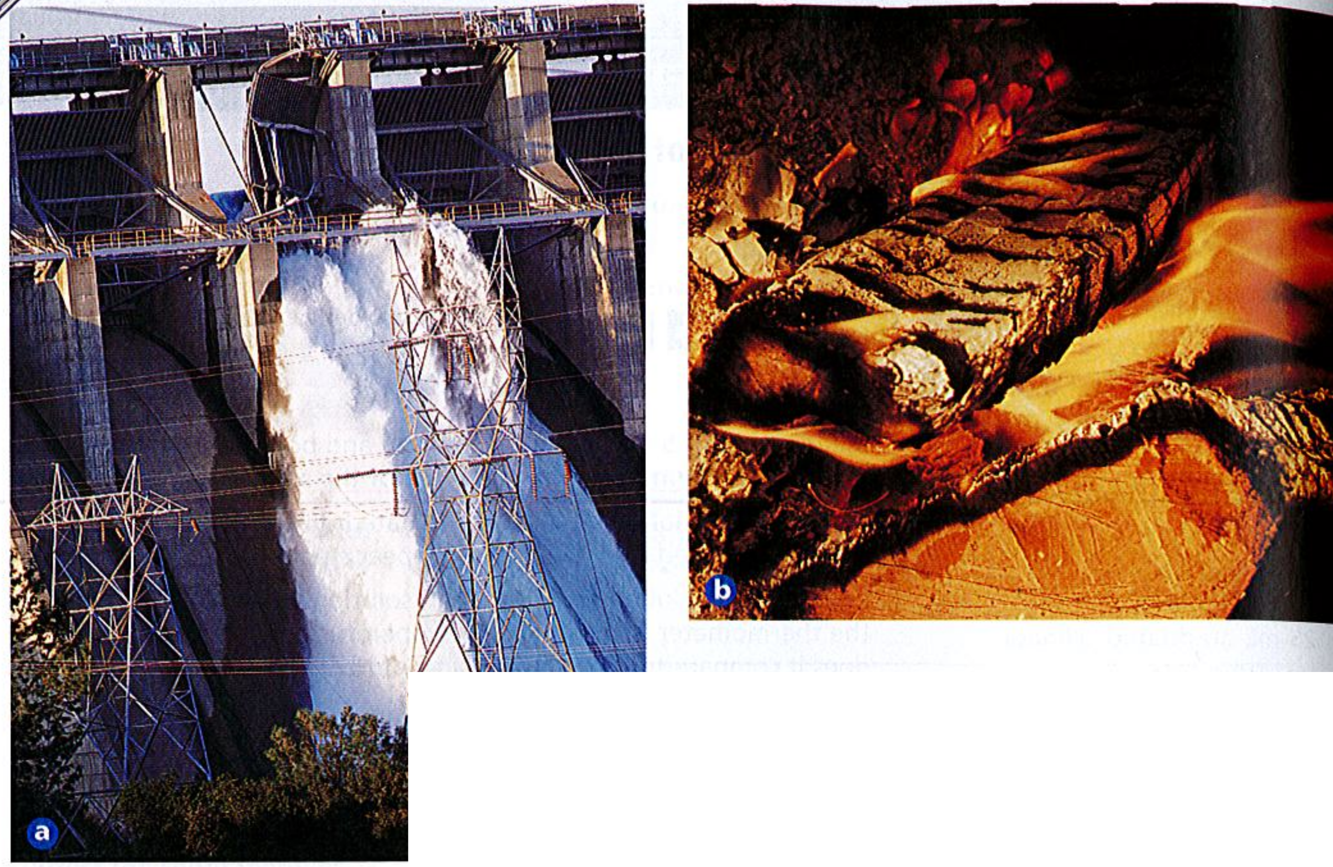


Figure 16-1

Energy is conserved in these energy transformations. In a, some of the potential energy of water stored behind Folsom Dam in California is converted to electrical energy. In b, the chemical potential energy stored in wood is converted to heat.

Law of conservation of energy When water rushes through turbines in the hydroelectric plant in **Figure 16-1a**, some of the water's potential energy is converted to electrical energy. When wood burns in a fireplace, as shown in **Figure 16-1b**, potential energy is liberated as heat. In both of these examples, energy changes from one form to another. But does the amount of energy change? No. As energy changes from one form to another, the total amount of energy remains constant. Energy is conserved. To better understand the conservation of energy, suppose you have money in two accounts at a bank and you transfer funds from one account to the other. Although the amount of money in each account has changed, the total amount of your money in the bank remains the same. When applied to energy, this analogy embodies the law of conservation of energy. The **law of conservation of energy** states that in any chemical reaction or physical process, energy can be converted from one form to another, but it is neither created nor destroyed.

Chemical potential energy The energy stored in a substance because of its composition is called **chemical potential energy.** Chemical potential energy plays an important role in chemical reactions. For example, consider octane (C_8H_{18}), one of the principal components of gasoline. The chemical potential energy of octane results from the arrangement of the carbon and hydrogen atoms and the strength of the bonds that join them. When gasoline burns in an automobile's engine, some of octane's stored energy is converted to work in moving the pistons, which ultimately move the wheels and propel the automobile and its occupants from place to place. However, much of the potential energy of octane is released as heat. **Heat,** which is represented by the symbol q, is energy that is in the process of flowing from a warmer object to a cooler object. When the warmer object loses heat, its temperature decreases. When the cooler object absorbs heat, its temperature rises.

Measuring heat The flow of energy and the resulting change in temperature are clues to how heat is measured. In the metric system of units, the amount of heat required to raise the temperature of one gram of pure water by one degree Celsius (1°C) is defined as a **calorie** (cal). You've heard much about the caloric content of various foods. When your body breaks down sugars and fats to form carbon dioxide and water, these exothermic reactions generate heat that can be measured in Calories. Note that the nutritional Calorie is capitalized. That's because one nutritional Calorie, also known as one kilocalorie (kcal), equals 1000 calories. Suppose you eat a tablespoon of butter. One tablespoon of butter "has" 100 Calories. That means that if the butter was burned completely to produce carbon dioxide and water, 100 kcal (100 000 cal) of heat would be released.

The SI unit of heat and energy is the **joule** (J). One joule is the equivalent of 0.2390 calories, or one calorie equals 4.184 joules. **Table 16-1** shows the relationships among calories, nutritional Calories, joules, and kilojoules (kJ) and the conversion factors you can use to convert from one unit to another.

Table 16-1

Relationships Among Energy Units

Relationship	Conversion factors
1 J = 0.2390 cal	$\frac{1\ J}{0.2390\ cal}$ $\frac{0.2390\ cal}{1\ J}$
1 cal = 4.184 J	$\frac{1\ cal}{4.184\ J}$ $\frac{4.184\ J}{1\ cal}$
1 kJ = 1000 J	$\frac{1\ kJ}{1000\ J}$ $\frac{1000\ J}{1\ kJ}$
1 Calorie = 1 kcal 1 kcal = 1000 cal	$\frac{1\ Calorie}{1000\ cal}$ $\frac{1000\ cal}{1\ kcal}$

EXAMPLE PROBLEM 16-1

Converting Energy Units

The breakfast shown in the photograph contains 230 nutritional Calories. How much energy in joules will this healthy breakfast supply?

1. Analyze the Problem

You are given an amount of energy in nutritional Calories. You must convert nutritional Calories to calories and then calories to joules.

Known	Unknown
amount of energy = 230 Calories	amount of energy = ? J

2. Solve for the Unknown

Use a conversion factor from **Table 16-1** to convert nutritional Calories to calories.

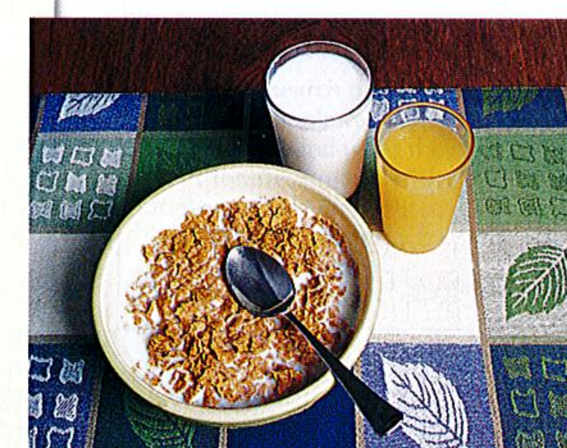
$$230\ \text{Calories} \times \frac{1000\ \text{cal}}{1\ \text{Calorie}} = 2.3 \times 10^5\ \text{cal}$$

Use a conversion factor to convert calories to joules.

$$2.3 \times 10^5\ \text{cal} \times \frac{4.184\ \text{J}}{1\ \text{cal}} = 9.6 \times 10^5\ \text{J}$$

3. Evaluate the Answer

The minimum number of significant figures used in the conversion is two, so the answer correctly has two digits. A value of the order of 10^5 or 10^6 is expected because the given number of kilocalories is of the order of 10^2 and it must be multiplied by 10^3 to convert it to calories. Then, the calories must be multiplied by a factor of approximately 4. Therefore, the answer is reasonable.



It's important to eat the appropriate number of Calories. It's also important that the foods you select provide the nutrients your body needs.

PRACTICE PROBLEMS

1. A fruit and oatmeal bar contains 142 nutritional Calories. Convert this energy to Joules.

2. An exothermic reaction releases 86.5 J. How many Calories of energy are released?

3. If an endothermic process absorbs 256 J, how many Calories are absorbed?