

Chemical Reactions

Simon Fraser/Scienc Photo Library/Photo Researchers

chapter preview

sections

- 1 Chemical Formulas and Equations
- 2 Rates of Chemical Reactions
Lab Physical or Chemical Change?
Lab Exothermic or Endothermic?



Virtual Lab What properties do elements have?

What chemical reactions happen at chemical plants?

Chemical plants like this one provide the starting materials for thousands of chemical reactions. The compact discs you listen to, personal items, such as shampoo and body lotion, and medicines all have their beginnings in a chemical plant.

Science Journal What additional types of products do you think are manufactured in a chemical plant?

Start-Up Activities



Identify a Chemical Reaction

You can see substances changing every day. Fuels burn, giving energy to cars and trucks. Green plants convert carbon dioxide and water into oxygen and sugar. Cooking an egg or baking bread causes changes too. These changes are called chemical reactions. In this lab you will observe a common chemical change.     

WARNING: Do not touch the test tube. It will be hot. Use extreme caution around an open flame. Point test tubes away from you and others.

1. Place 3 g of sugar into a large test tube.
2. Carefully light a laboratory burner.
3. Using a test-tube holder, hold the bottom of the test tube just above the flame for 45 s or until something happens with the sugar.
4. Observe any change that occurs.
5. **Think Critically** Describe in your Science Journal the changes that took place in the test tube. What do you think happened to the sugar? Was the substance that remained in the test tube after heating the same as the substance you started with?

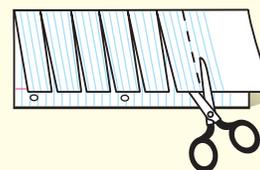
FOLDABLES™ Study Organizer

Chemical Reaction Make the following Foldable to help you understand chemical reactions.

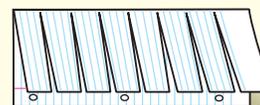
- STEP 1** Fold a vertical sheet of notebook paper in half lengthwise.



- STEP 2** Cut along every third line of only the top layer to form tabs.



- STEP 3** Label each tab.



Research Information Before you read the chapter, write several questions you have about chemical reactions on the front of the tabs. As you read, add more questions. Under the tabs of your Foldable, write answers to the questions you recorded on the tabs.



Preview this chapter's content and activities at ips.msscience.com

Chemical Formulas and Equations

as you read

What You'll Learn

- **Determine** whether or not a chemical reaction is occurring.
- **Determine** how to read and understand a balanced chemical equation.
- **Examine** some reactions that release energy and others that absorb energy.
- **Explain** the law of conservation of mass.

Why It's Important

Chemical reactions warm your home, cook your meals, digest your food, and power cars and trucks.

Review Vocabulary

atom: the smallest piece of matter that still retains the property of the element

New Vocabulary

- chemical reaction
- reactant
- product
- chemical equation
- endothermic reaction
- exothermic reaction

Physical or Chemical Change?

You can smell a rotten egg and see the smoke from a campfire. Signs like these tell you that a chemical reaction is taking place. Other evidence might be less obvious, but clues are always present to announce that a reaction is under way.

Matter can undergo two kinds of changes—physical and chemical. Physical changes in a substance affect only physical properties, such as its size and shape, or whether it is a solid, liquid, or gas. For example, when water freezes, its physical state changes from liquid to solid, but it's still water.

In contrast, chemical changes produce new substances that have properties different from those of the original substances. The rust on a bike's handlebars, for example, has properties different from those of the metal around it. Another example is the combination of two liquids that produce a precipitate, which is a solid, and a liquid. The reaction of silver nitrate and sodium chloride forms solid silver chloride and liquid sodium nitrate. A process that produces chemical change is a **chemical reaction**.

To compare physical and chemical changes, look at the newspaper shown in **Figure 1**. If you fold it, you change its size and shape, but it is still newspaper. Folding is a physical change. If you use it to start a fire, it will burn. Burning is a chemical change because new substances result. How can you recognize a chemical change? **Figure 2** shows what to look for.

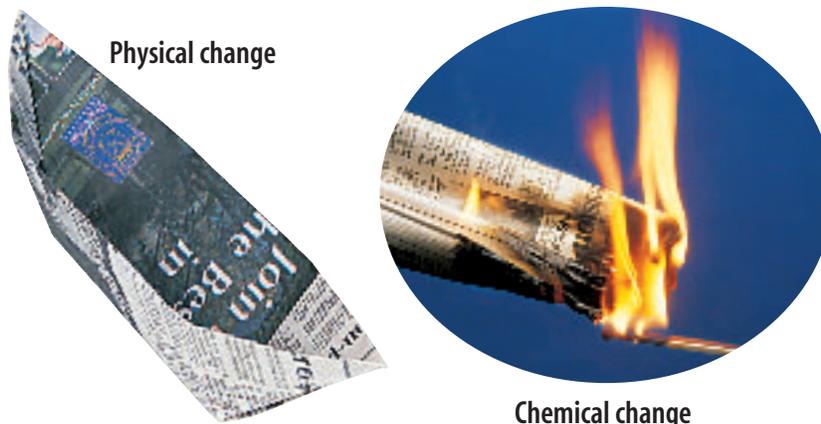
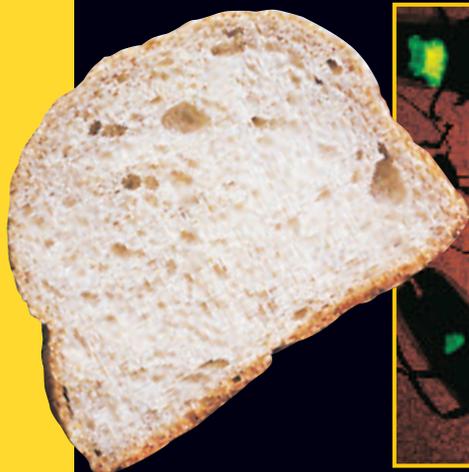


Figure 1 Newspaper can undergo both physical and chemical changes.

Figure 2

Chemical reactions take place when chemicals combine to form new substances. Your senses—sight, taste, hearing, smell, and touch—can help you detect chemical reactions in your environment.

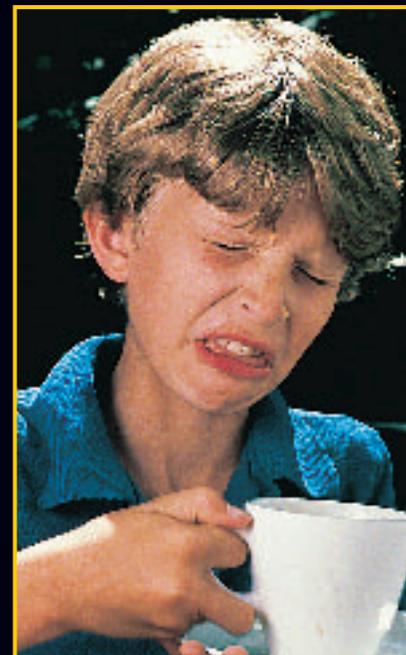


▲ SIGHT When you spot a firefly's bright glow, you are seeing a chemical reaction in progress—two chemicals are combining in the firefly's abdomen and releasing light in the process. The holes in a slice of bread are visible clues that sugar molecules were broken down by yeast cells in a chemical reaction that produces carbon dioxide gas. The gas caused the bread dough to rise.



▲ SMELL AND TOUCH Billowing clouds of acrid smoke and waves of intense heat indicate that chemical reactions are taking place in this burning forest.

▼ TASTE A boy grimaces after sipping milk that has gone sour due to a chemical reaction.



▲ HEARING A Russian cosmonaut hoists a flare into the air after landing in the ocean during a training exercise. The hissing sound of the burning flare is the result of a chemical reaction.

Chemical Equations

To describe a chemical reaction, you must know which substances react and which substances are formed in the reaction. The substances that react are called the reactants (see AK tunts). **Reactants** are the substances that exist before the reaction begins. The substances that form as a result of the reaction are called the **products**.

When you mix baking soda and vinegar, a vigorous chemical reaction occurs. The mixture bubbles and foams up inside the container, as you can see in **Figure 3**.

Baking soda and vinegar are the common names for the reactants in this reaction, but they also have chemical names. Baking soda is the compound sodium hydrogen carbonate (often called sodium bicarbonate), and vinegar is a solution of acetic (uh SEE tihk) acid in water. What are the products? You saw bubbles form when the reaction occurred, but is that enough of a description?

Describing What Happens Bubbles tell you that a gas has been produced, but they don't tell you what kind of gas. Are bubbles of gas the only product, or do some atoms from the vinegar and baking soda form something else? What goes on in the chemical reaction can be more than what you see with your eyes. Chemists try to find out which reactants are used and which products are formed in a chemical reaction. Then, they can write it in a shorthand form called a chemical equation. A **chemical equation** tells chemists at a glance the reactants, products, physical state, and the proportions of each substance present. This is very important as you will see later.

 **Reading Check** What does a chemical equation tell chemists?

Figure 3 The bubbles tell you that a chemical reaction has taken place.

Predict how you might find out whether a new substance has formed.



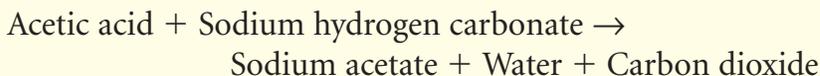
Table 1 Reactions Around the Home

Reactants		Products
Baking soda + Vinegar	→	Gas + White solid
Charcoal + Oxygen	→	Ash + Gas + Heat
Iron + Oxygen + Water	→	Rust
Silver + Hydrogen sulfide	→	Black tarnish + Gas
Gas (kitchen range) + Oxygen	→	Gas + Heat
Sliced apple + Oxygen	→	Apple turns brown

Using Words One way you can describe a chemical reaction is with an equation that uses words to name the reactants and products. The reactants are listed on the left side of an arrow, separated from each other by plus signs. The products are placed on the right side of the arrow, also separated by plus signs. The arrow between the reactants and products represents the changes that occur during the chemical reaction. When reading the equation, the arrow is read as *produces*.

You can begin to think of processes as chemical reactions even if you do not know the names of all the substances involved. **Table 1** can help you begin to think like a chemist. It shows the word equations for chemical reactions you might see around your home. See how many other reactions you can find. Look for the signs you have learned that indicate a reaction might be taking place. Then, try to write them in the form shown in the table.

Using Chemical Names Many chemicals used around the home have common names. For example, acetic acid dissolved in water is called vinegar. Some chemicals, such as baking soda, have two common names—it also is known as sodium bicarbonate. However, chemical names are usually used in word equations instead of common names. In the baking soda and vinegar reaction, you already know the chemical names of the reactants—sodium hydrogen carbonate and acetic acid. The names of the products are sodium acetate, water, and carbon dioxide. The word equation for the reaction is as follows.



Autumn Leaves A color change can indicate a chemical reaction. When leaves change colors in autumn, the reaction may not be what you expect. The bright yellow and orange are always in the leaves, but masked by green chlorophyll. When the growth season ends, more chlorophyll is broken down than produced. The orange and yellow colors become visible.

Mini LAB

Observing the Law of Conservation of Mass

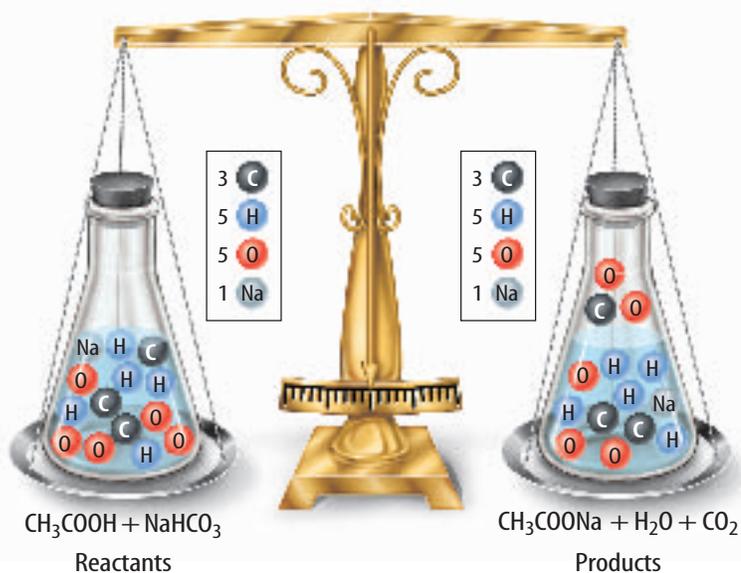
Procedure 

1. Place a piece of **steel wool** into a **medium test tube**. Seal the end of the test tube with a **balloon**.
2. Find the mass.
3. Using a test-tube holder, heat the bottom of the tube for two minutes in a **hot water bath** provided by your teacher. Allow the tube to cool completely.
4. Find the mass again.

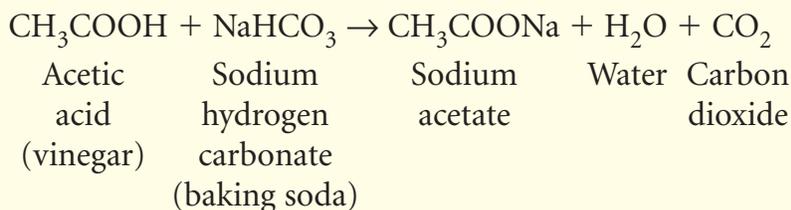
Analysis

1. What did you observe that showed a chemical reaction took place?
2. Compare the mass before and after the reaction.
3. Why was it important for the test tube to be sealed?

Figure 4 The law of conservation of mass states that the number and kind of atoms must be equal for products and reactants.



Using Formulas The word equation for the reaction of baking soda and vinegar is long. That's why chemists use chemical formulas to represent the chemical names of substances in the equation. You can convert a word equation into a chemical equation by substituting chemical formulas for the chemical names. For example, the chemical equation for the reaction between baking soda and vinegar can be written as follows:



Subscripts When you look at chemical formulas, notice the small numbers written to the right of the atoms. These numbers, called subscripts, tell you the number of atoms of each element in that compound. For example, the subscript 2 in CO_2 means that each molecule of carbon dioxide has two oxygen atoms. If an atom has no subscript, it means that only one atom of that element is in the compound, so carbon dioxide has only one carbon atom.

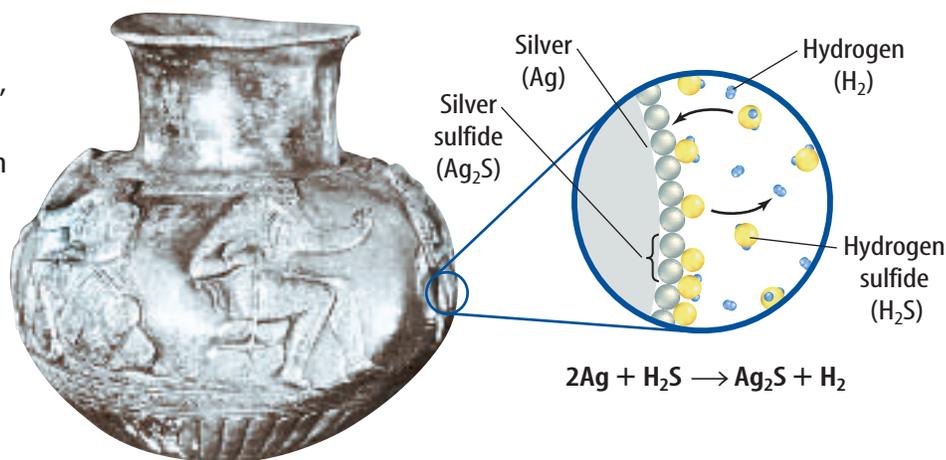
Conservation of Mass

What happens to the atoms in the reactants when they are converted into products? According to the law of conservation of mass, the mass of the products must be the same as the mass of the reactants in that chemical reaction. This principle was first stated by the French chemist Antoine Lavoisier (1743–1794), who is considered the first modern chemist. Lavoisier used logic and scientific methods

to study chemical reactions. He proved by his experiments that nothing is lost or created in chemical reactions.

He showed that chemical reactions are much like mathematical equations. In math equations, the right and left sides of the equation are numerically equal. Chemical equations are similar, but it is the number and kind of atoms that are equal on the two sides. Every atom that appears on the reactant side of the equation also appears on the product side, as shown in **Figure 4**. Atoms are never lost or created in a chemical reaction; however, they do change partners.

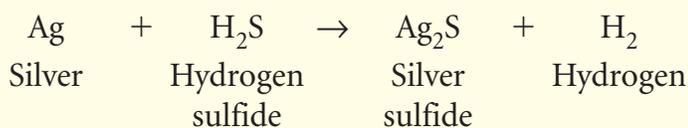
Figure 5 Keeping silver bright takes frequent polishing, especially in homes heated by gas. Sulfur compounds found in small concentrations in natural gas react with silver, forming black silver sulfide, Ag_2S .



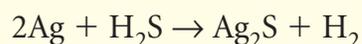
Balancing Chemical Equations

When you write the chemical equation for a reaction, you must observe the law of conservation of mass. Look back at **Figure 4**. It shows that when you count the number of carbon, hydrogen, oxygen, and sodium atoms on each side of the arrow in the equation, you find equal numbers of each kind of atom. This means the equation is balanced and the law of conservation of mass is observed.

Not all chemical equations are balanced so easily. For example, silver tarnishes, as in **Figure 5**, when it reacts with sulfur compounds in the air, such as hydrogen sulfide. The following unbalanced equation shows what happens when silver tarnishes.



Count the Atoms Count the number of atoms of each type in the reactants and in the products. The same numbers of hydrogen and sulfur atoms are on each side, but one silver atom is on the reactant side and two silver atoms are on the product side. This cannot be true. A chemical reaction cannot create a silver atom, so this equation does not represent the reaction correctly. Place a 2 in front of the reactant Ag and check to see if the equation is balanced. Recount the number of atoms of each type.



The equation is now balanced. There are an equal number of silver atoms in the reactants and the products. When balancing chemical equations, numbers are placed before the formulas as you did for Ag. These are called coefficients. However, never change the subscripts written to the right of the atoms in a formula. Changing these numbers changes the identity of the compound.



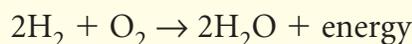
Topic: Chemical Equations

Visit ips.msscience.com for Web links to information about chemical equations and balancing them.

Activity Find a chemical reaction that takes place around your home or school. Write a chemical equation describing it.

Energy in Chemical Reactions

Often, energy is released or absorbed during a chemical reaction. The energy for the welding torch in **Figure 6** is released when hydrogen and oxygen combine to form water.



Energy Released Where does this energy come from? To answer this question, think about the chemical bonds that break and form when atoms gain, lose, or share electrons. When such a reaction takes place, bonds break in the reactants and new bonds form in the products. In reactions that release energy, the products are more stable, and their bonds have less energy than those of the reactants. The extra energy is released in various forms—light, sound, and heat.

Applying Math

Balancing Equations

CONSERVING MASS Methane and oxygen react to form carbon dioxide, water, and heat. You can see how mass is conserved by balancing the equation: $\text{CH}_4 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$.

Solution

1 *This is what you know:*

The number of atoms of C, H, and O in reactants and products.

2 *This is what you need to do:*

Make sure that the reactants and products have equal numbers of atoms of each element. Start with the reactant having the greatest number of atoms.

Reactants	Products	Action
$\text{CH}_4 + \text{O}_2$ have 4 H atoms	$\text{CO}_2 + \text{H}_2\text{O}$ have 2 H atoms	Need 2 more H atoms in Products Multiply H_2O by 2 to give 4 H atoms
$\text{CH}_4 + \text{O}_2$ have 2 O atoms	$\text{CO}_2 + \text{H}_2\text{O}$ have 4 O atoms	Need 2 more O atoms in Reactants Multiply O_2 by 2 to give 4 O atoms

The balanced equation is $\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$.

3 *Check your answer:*

Count the carbons, hydrogens, and oxygens on each side.

Practice Problems

1. Balance the equation $\text{Fe}_2\text{O}_3 + \text{CO} \rightarrow \text{Fe}_3\text{O}_4 + \text{CO}_2$.
2. Balance the equation $\text{Al} + \text{I}_2 \rightarrow \text{AlI}_3$.



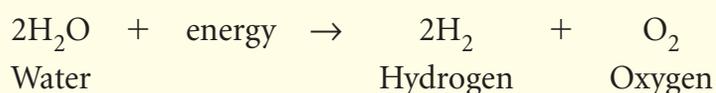
For more practice, visit
[ips.msscience.com/
math_practice](http://ips.msscience.com/math_practice)



Figure 6 This welding torch burns hydrogen and oxygen to produce temperatures above 3,000°C. It can even be used underwater.

Identify the products of this chemical reaction.

Energy Absorbed What happens when the reverse situation occurs? In reactions that absorb energy, the reactants are more stable, and their bonds have less energy than those of the products.



In this reaction the extra energy needed to form the products can be supplied in the form of electricity, as shown in **Figure 7**.

As you have seen, reactions can release or absorb energy of several kinds, including electricity, light, sound, and heat. When heat energy is gained or lost in reactions, special terms are used.

Endothermic (en doh THUR mihk) **reactions** absorb heat energy. **Exothermic** (ek soh THUR mihk) **reactions** release heat energy. You may notice that the root word *therm* refers to heat, as it does in thermos bottles and thermometers.

Heat Released You might already be familiar with several types of reactions that release heat. Burning is an exothermic chemical reaction in which a substance combines with oxygen to produce heat along with light, carbon dioxide, and water.

Reading Check *What type of chemical reaction is burning?*

Rapid Release Sometimes energy is released rapidly. For example, charcoal lighter fluid combines with oxygen in the air and produces enough heat to ignite a charcoal fire within a few minutes.

Figure 7 Electrical energy is needed to break water into its components. This is the reverse of the reaction that takes place in the welding torch shown in **Figure 6**.

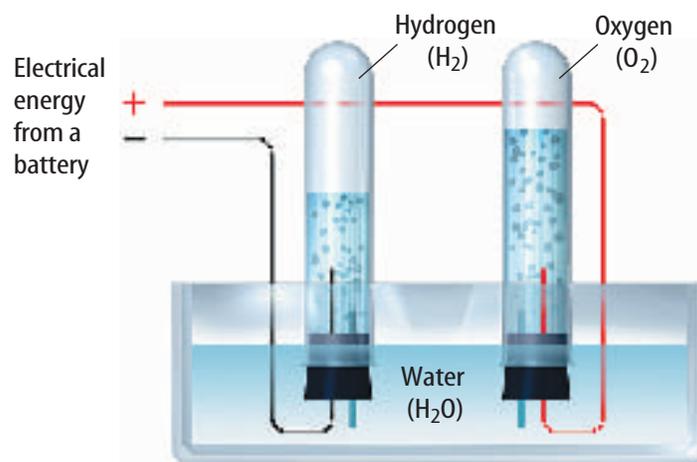


Figure 8 Two exothermic reactions are shown.

The charcoal fire to cook the food was started when lighter fluid combined rapidly with oxygen in air. The iron in the wheelbarrow combined slowly with oxygen in the air to form rust.



Slow reaction



Fast reaction

Slow Release Other materials also combine with oxygen but release heat so slowly that you cannot see or feel it happen. This is the case when iron combines with oxygen in the air to form rust. The slow heat release from a reaction also is used in heat packs that can keep your hands warm for several hours. Fast and slow energy release are compared in **Figure 8**.

Heat Absorbed Some chemical reactions and physical processes need to have heat energy added before they can proceed. An example of an endothermic physical process that absorbs heat energy is the cold pack shown in **Figure 9**.

The heavy plastic cold pack holds ammonium nitrate and water. The two substances are separated by a plastic divider. When you squeeze the bag, you break the divider so that the ammonium nitrate dissolves in the water. The dissolving process absorbs heat energy, which must come from the surrounding environment—the surrounding air or your skin after you place the pack on the injury.

Figure 9 The heat energy needed to dissolve the ammonium nitrate in this cold pack comes from the surrounding environment.

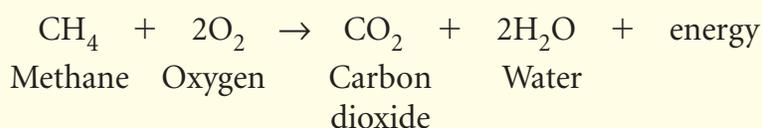


Energy in the Equation The word *energy* often is written in equations as either a reactant or a product. Energy written as a reactant helps you think of energy as a necessary ingredient for the reaction to take place. For example, electrical energy is needed to break up water into hydrogen and oxygen. It is important to know that energy must be added to make this reaction occur.

Similarly, in the equation for an exothermic reaction, the word *energy* often is written along with the products. This tells you that energy is released. You include energy when writing the reaction that takes place between oxygen and methane in natural gas when you cook on a gas range, as shown in **Figure 10**. This heat energy cooks your food.



Figure 10 Energy from a chemical reaction is used to cook. **Determine** if energy is used as a reactant or a product in this reaction.



Although it is not necessary, writing the word *energy* can draw attention to an important aspect of the equation.

section 1 review

Summary

Physical or Chemical Change?

- Matter can undergo physical and chemical changes.
- A chemical reaction produces chemical changes.

Chemical Equations

- A chemical equation describes a chemical reaction.
- Chemical formulas represent chemical names for substances.
- A balanced chemical equation has the same number of atoms of each kind on both sides of the equation.

Energy in Chemical Reactions

- Endothermic reactions absorb heat energy.
- Exothermic reactions release heat energy.

Self Check

1. **Determine** if each of these equations is balanced. Why or why not?
 - a. $\text{Ca} + \text{Cl}_2 \rightarrow \text{CaCl}_2$
 - b. $\text{Zn} + \text{Ag}_2\text{S} \rightarrow \text{ZnS} + \text{Ag}$
2. **Describe** what evidence might tell you that a chemical reaction has occurred.
3. **Think Critically** After a fire, the ashes have less mass and take up less space than the trees and vegetation before the fire. How can this be explained in terms of the Law of Conservation of Mass?

Applying Math

4. **Calculate** The equation for the decomposition of silver oxide is $2\text{Ag}_2\text{O} \rightarrow 4\text{Ag} + \text{O}_2$. Set up a ratio to calculate the number of oxygen molecules released when 1 g of silver oxide is broken down. There are 2.6×10^{21} molecules in 1 g of silver oxide.

Rates of Chemical Reactions

as you read

What You'll Learn

- **Determine** how to describe and measure the speed of a chemical reaction.
- **Identify** how chemical reactions can be speeded up or slowed down.

Why It's Important

Speeding up useful reactions and slowing down destructive ones can be helpful.

Review Vocabulary

state of matter: physical property that is dependent on temperature and pressure and occurs in four forms—solid, liquid, gas, or plasma

New Vocabulary

- activation energy
- rate of reaction
- concentration
- inhibitor
- catalyst
- enzyme

How Fast?

Fireworks explode in rapid succession on a summer night. Old copper pennies darken slowly while they lie forgotten in a drawer. Cooking an egg for two minutes instead of five minutes makes a difference in the firmness of the yolk. The amount of time you leave coloring solution on your hair must be timed accurately to give the color you want. Chemical reactions are common in your life. However, notice from these examples that time has something to do with many of them. As you can see in **Figure 11**, not all chemical reactions take place at the same rate.

Some reactions, such as fireworks or lighting a campfire, need help to get going. You may also notice that others seem to start on their own. In this section, you will also learn about factors that make reactions speed up or slow down once they get going.

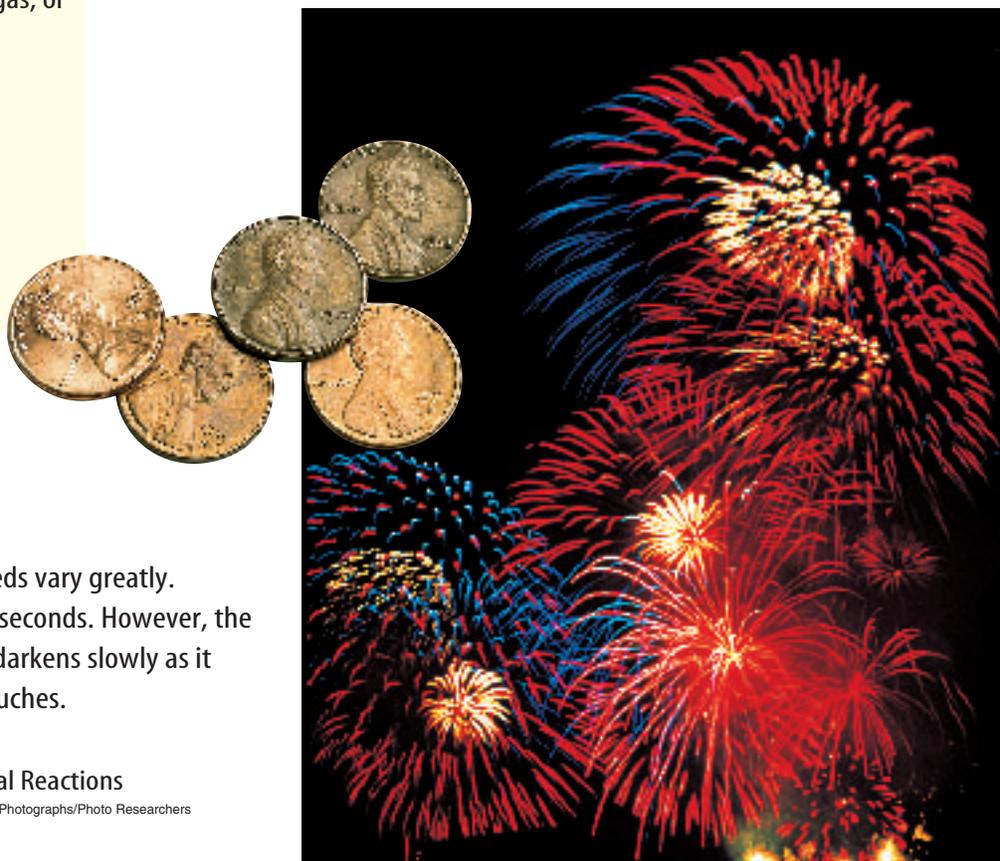


Figure 11 Reaction speeds vary greatly. Fireworks are over in a few seconds. However, the copper coating on pennies darkens slowly as it reacts with substances it touches.

Activation Energy—Starting a Reaction

Before a reaction can start, molecules of the reactants have to bump into each other, or collide. This makes sense because to form new chemical bonds, atoms have to be close together. But, not just any collision will do. The collision must be strong enough. This means the reactants must smash into each other with a certain amount of energy. Anything less, and the reaction will not occur. Why is this true?

To form new bonds in the product, old bonds must break in the reactants, and breaking bonds takes energy. To start any chemical reaction, a minimum amount of energy is needed. This energy is called the **activation energy** of the reaction.

✓ Reading Check

What term describes the minimum amount of energy needed to start a reaction?

What about reactions that release energy? Is there an activation energy for these reactions too? Yes, even though they release energy later, these reactions also need enough energy to start.

One example of a reaction that needs energy to start is the burning of gasoline. You have probably seen movies in which a car plunges over a cliff, lands on the rocks below, and suddenly bursts into flames. But if some gasoline is spilled accidentally while filling a gas tank, it probably will evaporate harmlessly in a short time.

Why doesn't this spilled gasoline explode as it does in the movies? The reason is that gasoline needs energy to start burning. That is why there are signs at filling stations warning you not to smoke. Other signs advise you to turn off the ignition, not to use mobile phones, and not to reenter the car until fueling is complete.

This is similar to the lighting of the Olympic Cauldron, as shown in **Figure 12**. Cauldrons designed for each Olympics contain highly flammable materials that cannot be extinguished by high winds or rain. However, they do not ignite until the opening ceremonies when a runner lights the cauldron using a flame that was kindled in Olympia, Greece, the site of the original Olympic Games.



Science  online

Topic: Olympic Torch

Visit ips.msscience.com for Web links to information about the Olympic Torch.

Activity With each new Olympics, the host city devises a new Olympic Torch. Research the process that goes into developing the torch and the fuel it uses.

Figure 12 Most fuels need energy to ignite. The Olympic Torch, held by Cathy Freeman in the 2000 Olympics, provided the activation energy required to light the fuel in the cauldron.



Figure 13 The diminishing amount of wax in this candle as it burns indicates the rate of the reaction.

Reaction Rate

Many physical processes are measured in terms of a rate. A rate tells you how much something changes over a given period of time. For example, the rate or speed at which you run or ride your bike is the distance you move divided by the time it took you to move that distance. You may jog at a rate of 8 km/h.

Chemical reactions have rates, too. The **rate of reaction** tells how fast a reaction occurs after it has started. To find the rate of a reaction, you can measure either how quickly one of the reactants is consumed or how quickly one of the products is created, as in **Figure 13**. Both measurements tell how the amount of a substance changes per unit of time.

✓ Reading Check

What can you measure to determine the rate of a reaction?

Reaction rate is important in industry because the faster the product can be made, the less it usually costs. However, sometimes fast rates of reaction are undesirable such as the rates of reactions that cause food spoilage. In this case, the slower the reaction rate, the longer the food will stay edible. What conditions control the reaction rate, and how can the rate be changed?

Temperature Changes Rate You can keep the food you buy at the store from spoiling so quickly by putting it in the refrigerator or freezer, as in **Figure 14**. Food spoiling is a chemical reaction. Lowering the temperature of the food slows the rate of this reaction.

Figure 14 Refrigerated foods must be kept below a certain temperature to slow spoilage. These grapes prove that spoilage, a chemical reaction, has occurred.



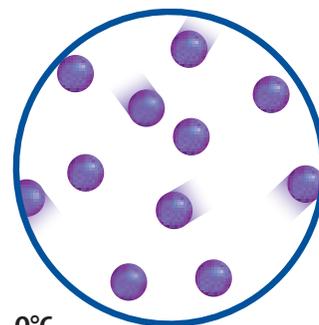


Meat and fish decompose faster at higher temperatures, producing toxins that can make you sick. Keeping these foods chilled slows the decomposition process. Bacteria grow faster at higher temperatures, too, so they reach dangerous levels sooner. Eggs may contain such bacteria, but the heat required to cook eggs also kills bacteria, so hard-cooked eggs are safer to eat than soft-cooked or raw eggs.

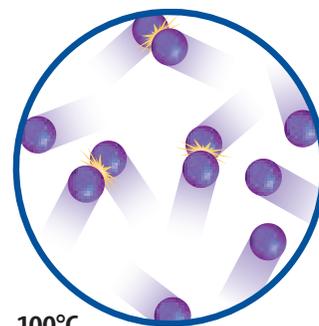
Temperature Affects Rate Most chemical reactions speed up when temperature increases. This is because atoms and molecules are always in motion, and they move faster at higher temperatures, as shown in **Figure 15**. Faster molecules collide with each other more often and with greater energy than slower molecules do, so collisions are more likely to provide enough energy to break the old bonds. This is the activation energy.

The high temperature inside an oven speeds up the chemical reactions that turn a liquid cake batter into a more solid, spongy cake. This works the other way, too. Lowering the temperature slows down most reactions. If you set the oven temperature too low, your cake will not bake properly.

Concentration Affects Rate The closer reactant atoms and molecules are to each other, the greater the chance of collisions between them and the faster the reaction rate. It's like the situation shown in **Figure 16**. When you try to walk through a crowded train station, you're more likely to bump into other people than if the station were not so crowded. The amount of substance present in a certain volume is called the **concentration** of that substance. If you increase the concentration, you increase the number of particles of a substance per unit of volume.



0°C

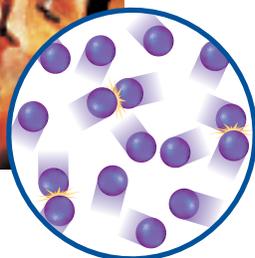


100°C

Figure 15 Molecules collide more frequently at higher temperatures than at lower temperatures. This means they are more likely to react.



Collisions are more frequent in a concentrated solution.



Collisions are less frequent in a dilute solution.

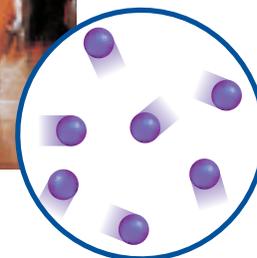


Figure 16 People are more likely to collide in crowds. Molecules behave similarly.

Figure 17 Iron atoms trapped inside this steel beam cannot react with oxygen quickly. More iron atoms are exposed to oxygen molecules in this steel wool, so the reaction speeds up.



Mini LAB

Identifying Inhibitors

Procedure

1. Look at the ingredients listed on **packages of cereals and crackers** in your kitchen.
2. Note the preservatives listed. These are chemical inhibitors.
3. Compare the date on the box with the approximate date the box was purchased to estimate shelf life.

Analysis

1. What is the average shelf life of these products?
2. Why is increased shelf life of such products important?



Surface Area Affects Rate The exposed surface area of reactant particles also affects how fast the reaction can occur. You can quickly start a campfire with small twigs, but starting a fire with only large logs would probably not work.

Only the atoms or molecules in the outer layer of the reactant material can touch the other reactants and react. **Figure 17A** shows that when particles are large, most of the iron atoms are stuck inside and can't react. In **Figure 17B**, more of the reactant atoms are exposed to the oxygen and can react.

Slowing Down Reactions

Sometimes reactions occur too quickly. For example, food and medications can undergo chemical reactions that cause them to spoil or lose their effectiveness too rapidly. Luckily, these reactions can be slowed down.

A substance that slows down a chemical reaction is called an **inhibitor**. An inhibitor makes the formation of a certain amount of product take longer. Some inhibitors completely stop reactions. Many cereals and cereal boxes contain the compound butylated hydroxytoluene, or BHT. The BHT slows the spoiling of the cereal and increases its shelf life.

Figure 18 BHT, an inhibitor, is found in many cereals and cereal boxes.



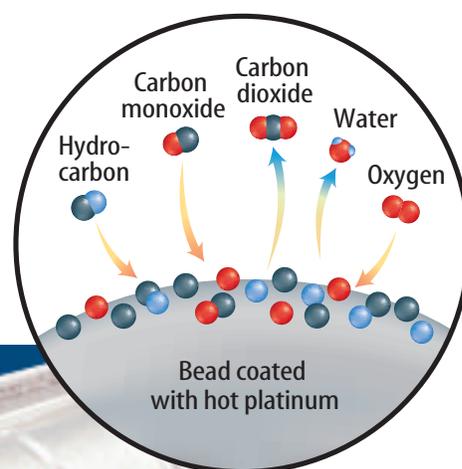
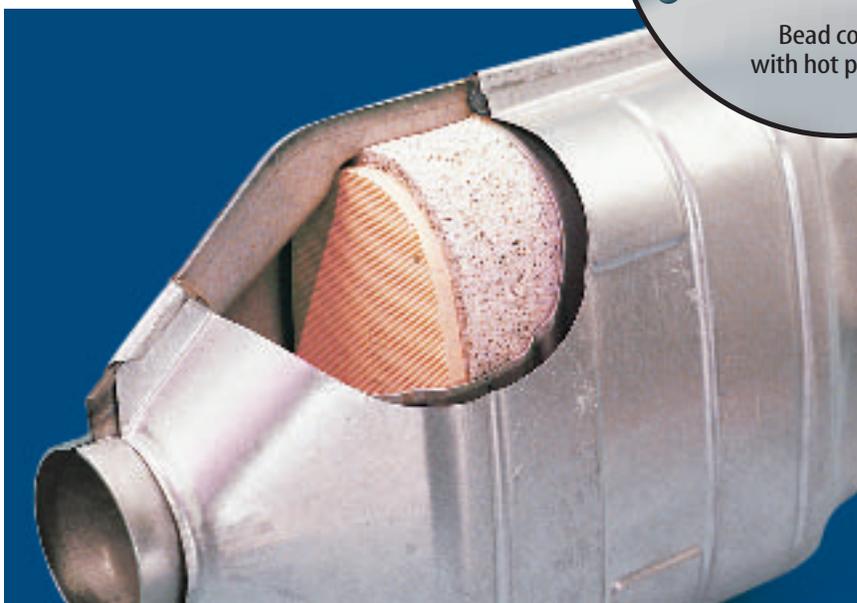
Speeding Up Reactions

Is it possible to speed up a chemical reaction? Yes, you can add a catalyst (KAT uh lihst). A **catalyst** is a substance that speeds up a chemical reaction. Catalysts do not appear in chemical equations, because they are not changed permanently or used up. A reaction using a catalyst will not produce more product than a reaction without a catalyst, but it will produce the same amount of product faster.

 **Reading Check** *What does a catalyst do in a chemical reaction?*

How does a catalyst work? Many catalysts speed up reaction rates by providing a surface for the reaction to take place. Sometimes the reacting molecules are held in a particular position that favors reaction. Other catalysts reduce the activation energy needed to start the reaction. When the activation energy is reduced, the reaction rate increases.

Catalytic Converters Catalysts are used in the exhaust systems of cars and trucks to aid fuel combustion. The exhaust passes through the catalyst, often in the form of beads coated with metals such as platinum or rhodium. Catalysts speed the reactions that change incompletely burned substances that are harmful, such as carbon monoxide, into less harmful substances, such as carbon dioxide. Similarly, hydrocarbons are changed into carbon dioxide and water. The result of these reactions is cleaner air. These reactions are shown in **Figure 19**.



Breathe Easy The Clean Air Act of 1970 required the reduction of 90 percent of automobile tailpipe emissions. The reduction of emissions included the amount of hydrocarbons and carbon monoxide released. Automakers did not have the technology to meet this new standard. After much hard work, the result of this legislation was the introduction of the catalytic converter in 1975.

Figure 19 Catalytic converters help to complete combustion of fuel. Hot exhaust gases pass over the surfaces of metal-coated beads. On the surface of the beads, carbon monoxide and hydrocarbons are converted to CO_2 and H_2O .



Figure 20 The enzymes in meat tenderizer break down protein in meat, making it more tender.

other catalysts, enzymes function by positioning the reacting molecules so that their structures fit together properly. Enzymes are a kind of chemical specialist—enzymes exist to carry out each type of reaction in your body.

Other Uses Enzymes work outside your body, too. One class of enzymes, called proteases (PROH tee ay ses), specializes in protein reactions. They work within cells to break down large, complex molecules called proteins. The meat tenderizer shown in **Figure 20** contains proteases that break down protein in meat, making it more tender. Contact lens cleaning solutions also contain proteases that break down proteins from your eyes that can collect on your lenses and cloud your view.

section 2 review

Summary

Chemical Reactions

- To form new bonds in the product, old bonds must break in the reactants. This takes energy.
- Activation energy is the minimum quantity of energy needed to start a reaction.

Reaction Rate

- The rate of reaction tells you how fast a reaction occurs.
- Temperature, concentration, and surface area affect the rate of reaction.

Inhibitors and Catalysts

- Inhibitors slow down reactions. Catalysts speed up reactions.
- Enzymes are catalysts that speed up or slow down reactions for your cells.

Self Check

1. **Describe** how you can measure reaction rates.
2. **Explain** in the general reaction $A + B + \text{energy} \rightarrow C$, how the following will affect the reaction rate.
 - a. increasing the temperature
 - b. decreasing the reactant concentration
3. **Describe** how catalysts work to speed up chemical reactions.
4. **Think Critically** Explain why a jar of spaghetti sauce can be stored for weeks on the shelf in the market but must be placed in the refrigerator after it is opened.

Applying Math

5. **Solve One-Step Equations** A chemical reaction is proceeding at a rate of 2 g of product every 45 s. How long will it take to obtain 50 g of product?

Physical or Chemical Change?

Real-World Question

Matter can undergo two kinds of changes—physical and chemical. A physical change affects the physical properties. When a chemical change takes place, a new product is produced. How can a scientist tell if a chemical change took place?

Goals

- **Determine** if a physical or chemical change took place.

Materials

500-mL Erlenmeyer flask
 1,000-mL graduated cylinder
 one-hole stopper with 15-cm length of glass tube inserted
 1,000-mL beaker
 45-cm length of rubber (or plastic) tubing
 stopwatch or clock with second hand
 weighing dish balance
 baking soda vinegar

Safety Precautions



WARNING: *Vinegar (acetic acid) may cause skin and eye irritation.*

Procedure

1. Measure 300 mL of water. Pour water into 500-mL Erlenmeyer flask.
2. Weigh 15 g of baking soda. Carefully pour the baking soda into the flask. Swirl the flask until the solution is clear.
3. Insert the rubber stopper with the glass tubing into the flask.
4. Measure 600 mL of water and pour into the 1,000-mL beaker.



5. Attach one end of the rubber tubing to the top of the glass tubing. Place the other end of the rubber tubing in the beaker. Be sure the rubber tubing remains under the water.
6. Remove the stopper from the flask. Carefully add 250 mL of vinegar to the flask. Replace the stopper.
7. Count the number of bubbles coming into the beaker for 20 s. Repeat this two more times.
8. Record your data in your Science Journal.

Conclude and Apply

1. **Describe** what you observed in the flask after the acid was added to the baking soda solution.
2. **Classify** Was this a physical or chemical change? How do you know?
3. **Analyze Results** Was this process endothermic or exothermic?
4. **Calculate** the average reaction rate based on the number of bubbles per second.

Communicating Your Data

Compare your results with those of other students in your class.

EXOTHERMIC OR ENDOTHERMIC?

Goals

- **Design** an experiment to test whether a reaction is exothermic or endothermic.
- **Measure** the temperature change caused by a chemical reaction.

Possible Materials

test tubes (8)
 test-tube rack
 3% hydrogen peroxide solution
 raw liver
 raw potato
 thermometer
 stopwatch
 clock with second hand
 25-mL graduated cylinder

Safety Precautions



WARNING: *Hydrogen peroxide can irritate skin and eyes and damage clothing.* Be careful when handling glass thermometers. Test tubes containing hydrogen peroxide should be placed and kept in racks. Dispose of materials as directed by your teacher. Wash your hands when you complete this lab.

Real-World Question

Energy is always a part of a chemical reaction. Some reactions need energy to start. Other reactions release energy into the environment. What evidence can you find to show that a reaction between hydrogen peroxide and liver or potato is exothermic or endothermic? Think about the difference between these two types of reactions.



Form a Hypothesis

Make a hypothesis that describes how you can use the reactions between hydrogen peroxide and liver or potato to determine whether a reaction is exothermic or endothermic.

Test Your Hypothesis

Make a Plan

1. As a group, look at the list of materials. Decide which procedure you will use to test your hypothesis, and which measurements you will make.
2. **Decide** how you will detect the heat released to the environment during the reaction. Determine how many measurements you will need to make during a reaction.
3. You will get more accurate data if you repeat each experiment several times. Each repeated experiment is called a trial. Use the average of all the trials as your data for supporting your hypothesis.
4. **Decide** what the variables are and what your control will be.
5. **Copy** the data table in your Science Journal before you begin to carry out your experiment.

Follow Your Plan

1. Make sure your teacher approves your plan before you start.
2. Carry out your plan.
3. **Record** your measurements immediately in your data table.
4. **Calculate** the averages of your trial results and record them in your Science Journal.

Using Scientific Methods

Analyze Your Data

1. Can you infer that a chemical reaction took place? What evidence did you observe to support this?
2. **Identify** what the variables were in this experiment.
3. **Identify** the control.

Temperature After Adding Liver/Potato

Trial	Temperature After Adding Liver (°C)		Temperature After Adding Potato (°C)	
	Starting	After ____ min	Starting	After ____ min
1				
2				
3				
4				

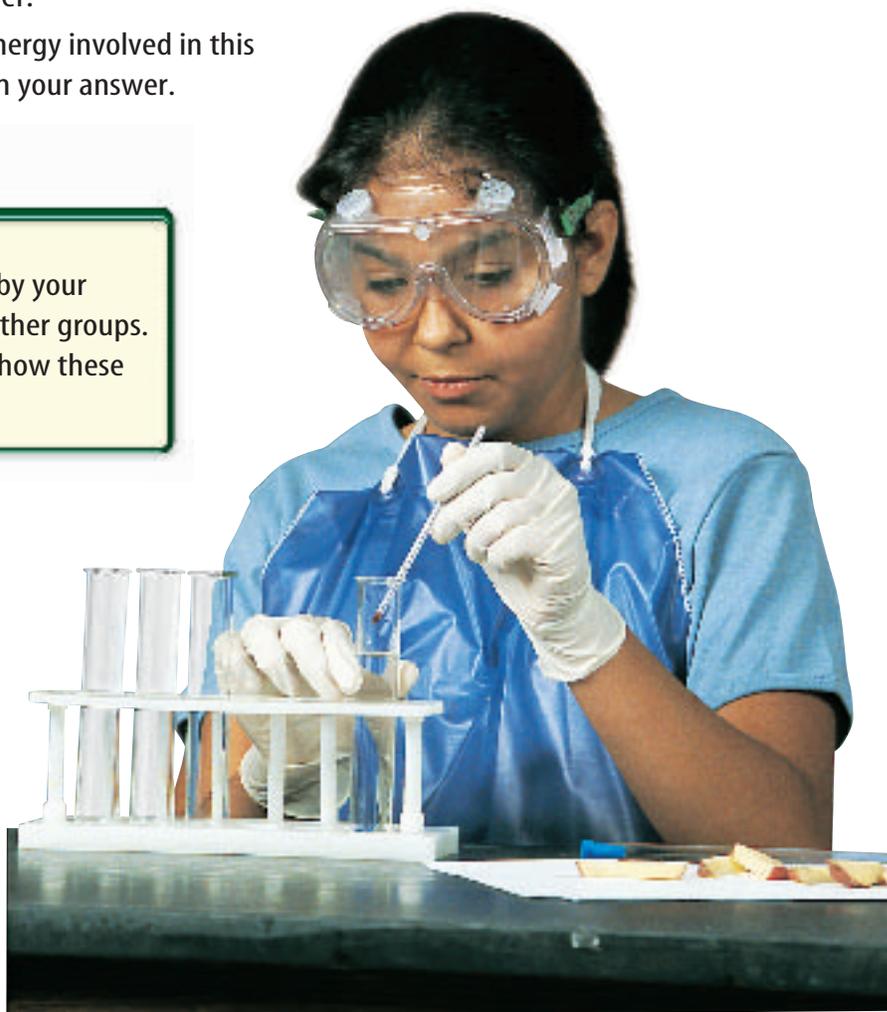
Do not write in this book.

Conclude and Apply

1. Do your observations allow you to distinguish between an exothermic reaction and an endothermic reaction? Use your data to explain your answer.
2. Where do you think that the energy involved in this experiment came from? Explain your answer.

Communicating Your Data

Compare the results obtained by your group with those obtained by other groups. Are there differences? **Explain** how these might have occurred.



Synthetic Diamonds

Natural
Diamond



Almost the
Real Thing



Synthetic
Diamond

Diamonds are the most dazzling, most dramatic, most valuable natural objects on Earth. Strangely, these beautiful objects are made of carbon, the same material graphite—the stuff found in pencils—is made of. So why is a diamond hard and clear and graphite soft and black? A diamond's hardness is a result of how strongly its atoms are linked. What makes a diamond transparent is the way its crystals are arranged. The carbon in a diamond is almost completely pure, with trace amounts of boron and nitrogen in it. These elements account for the many shades of color found in diamonds.

A diamond is the hardest naturally occurring substance on Earth. It's so hard, only a diamond can scratch another diamond. Diamonds are impervious to heat and household chemicals. Their crystal structure allows them to be split (or crushed) along particular lines.

Diamonds are made when carbon is squeezed at high pressures and temperatures in Earth's upper mantle, about 150 km beneath the surface. At that depth, the temperature is about 1,400°C, and the pressure is about 55,000 atmospheres greater than the pressure at sea level.

As early as the 1850s, scientists tried to convert graphite into diamonds. It wasn't until 1954 that researchers produced the first synthetic diamonds by compressing carbon under extremely high pressure and heat. Scientists converted graphite powder into tiny diamond crystals using pressure of more than 68,000 atm, and a temperature of about 1,700°C for about 16 hours.

Synthetic diamonds are human-made, but they're not fake. They have all the properties of natural diamonds, from hardness to excellent heat conductivity. Experts claim to be able to detect synthetics because they contain tiny amounts of metal (used in their manufacturing process) and have a different luminescence than natural diamonds. In fact, most synthetics are made for industrial use. One major reason is that making small synthetic diamonds is cheaper than finding small natural ones. The other reason is that synthetics can be made to a required size and shape. Still, if new techniques bring down the cost of producing large, gem-quality synthetic diamonds, they may one day compete with natural diamonds as jewelry.

Research Investigate the history of diamonds—natural and synthetic. Explain the differences between them and their uses. Share your findings with the class.

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Reviewing Main Ideas

Section 1 Formulas and Chemical Equations

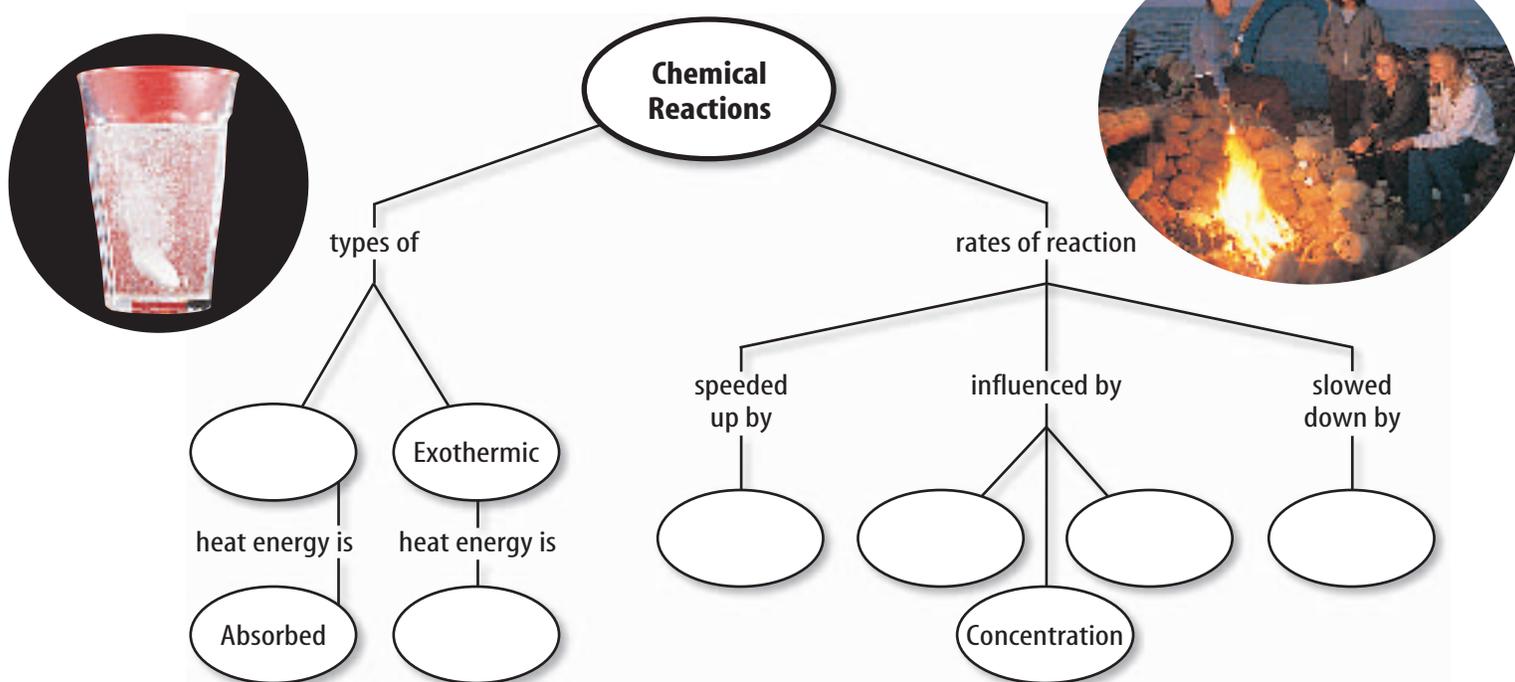
1. Chemical reactions often cause observable changes, such as a change in color or odor, a release or absorption of heat or light, or a release of gas.
2. A chemical equation is a shorthand method of writing what happens in a chemical reaction. Chemical equations use symbols to represent the reactants and products of a reaction, and sometimes show whether energy is produced or absorbed.
3. The law of conservation of mass requires that the same number of atoms of each element be in the products as in the reactants of a chemical equation. This is true in every balanced chemical equation.

Section 2 Rates of Chemical Reactions

1. The rate of reaction is a measure of how quickly a reaction occurs.
2. All reactions have an activation energy—a certain minimum amount of energy required to start the reaction.
3. The rate of a chemical reaction can be influenced by the temperature, the concentration of the reactants, and the exposed surface area of the reactant particles.
4. Catalysts can speed up a reaction without being used up. Inhibitors slow down the rate of reaction.
5. Enzymes are protein molecules that act as catalysts in your body's cells.

Visualizing Main Ideas

Copy and complete the following concept map on chemical reactions.



Using Vocabulary

activation energy p.201	enzyme p.206
catalyst p.205	exothermic reaction p.197
chemical equation p.192	inhibitor p.204
chemical reaction p.190	product p.192
concentration p.203	rate of reaction p.202
endothermic reaction p.197	reactant p.192

Explain the differences between the vocabulary terms in each of the following sets.

- exothermic reaction—endothermic reaction
- activation energy—rate of reaction
- reactant—product
- catalyst—inhibitor
- concentration—rate of reaction
- chemical equation—reactant
- inhibitor—product
- catalyst—chemical equation
- rate of reaction—enzyme

Checking Concepts

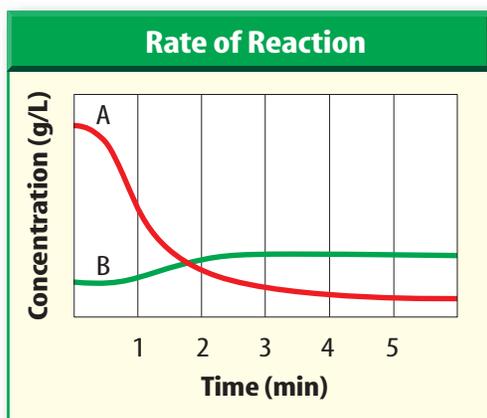
Choose the word or phrase that best answers the question.

- Which statement about the law of conservation of mass is NOT true?
 - The mass of reactants must equal the mass of products.
 - All the atoms on the reactant side of an equation are also on the product side.
 - The reaction creates new types of atoms.
 - Atoms are not lost, but are rearranged.
- To slow down a chemical reaction, what should you add?
 - catalyst
 - reactant
 - inhibitor
 - enzyme
- Which of these is a chemical change?
 - Paper is shredded.
 - Liquid wax turns solid.
 - A raw egg is broken.
 - Soap scum forms.
- Which of these reactions releases heat energy?
 - unbalanced
 - balanced
 - exothermic
 - endothermic
- A balanced chemical equation must have the same number of which of these on both sides of the equation?
 - atoms
 - reactants
 - molecules
 - compounds
- What does NOT affect reaction rate?
 - balancing
 - temperature
 - surface area
 - concentration
- Which is NOT a balanced equation?
 - $\text{CuCl}_2 + \text{H}_2\text{S} \rightarrow \text{CuS} + 2\text{HCl}$
 - $\text{AgNO}_3 + \text{NaI} \rightarrow \text{AgI} + \text{NaNO}_3$
 - $2\text{C}_2\text{H}_6 + 7\text{O}_2 \rightarrow 4\text{CO}_2 + 6\text{H}_2\text{O}$
 - $\text{MgO} + \text{Fe} \rightarrow \text{Fe}_2\text{O}_3 + \text{Mg}$
- Which is NOT evidence that a chemical reaction has occurred?
 - Milk tastes sour.
 - Steam condenses on a cold window.
 - A strong odor comes from a broken egg.
 - A slice of raw potato darkens.
- Which of the following would decrease the rate of a chemical reaction?
 - increase the temperature
 - reduce the concentration of a reactant
 - increase the concentration of a reactant
 - add a catalyst
- Which of these describes a catalyst?
 - It is a reactant.
 - It speeds up a reaction.
 - It appears in the chemical equation.
 - It can be used in place of an inhibitor.

Thinking Critically

- 20. Cause and Effect** Pickled cucumbers remain edible much longer than fresh cucumbers do. Explain.
- 21. Analyze** A beaker of water in sunlight becomes warm. Has a chemical reaction occurred? Explain.
- 22. Distinguish** if $2\text{Ag} + \text{S}$ is the same as Ag_2S . Explain.
- 23. Infer** Apple slices can be kept from browning by brushing them with lemon juice. Infer what role lemon juice plays in this case.
- 24. Draw a Conclusion** Chili can be made using ground meat or chunks of meat. Which would you choose, if you were in a hurry? Explain.

Use the graph below to answer question 25.



- 25. Interpret Scientific Illustrations** The two curves on the graph represent the concentrations of compounds A (blue) and B (red) during a chemical reaction.
- Which compound is a reactant?
 - Which compound is a product?
 - During which time period is the concentration of the reactant changing most rapidly?

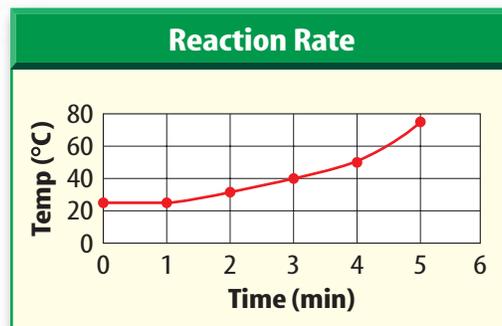
- 26. Form a Hypothesis** You are cleaning out a cabinet beneath the kitchen sink and find an unused steel wool scrub pad that has rusted completely. Will the remains of this pad weigh more or less than when it was new? Explain.

Performance Activities

- 27. Poster** Make a list of the preservatives in the food you eat in one day. Present your findings to your class in a poster.

Applying Math

Use the graph below to answer question 28.



- 28. Reaction Rates** In the reaction graph above, how long does it take the reaction to reach 50°C ?
- 29. Chemical Equation** In the following chemical equation, $3\text{Na} + \text{AlCl}_3 \rightarrow 3\text{NaCl} + \text{Al}$, how many aluminum molecules will be produced if you have 30 molecules of sodium?
- 30. Catalysis** A zinc catalyst is used to reduce the reaction time by 30%. If the normal time for the reaction to finish is 3 h, how long will it take with the catalyst?
- 31. Molecules** Silver has 6.023×10^{23} molecules per 107.9 g. How many molecules are there if you have
- 53.95 g?
 - 323.7 g?
 - 10.79 g?

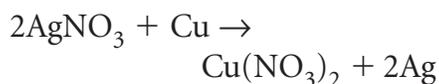
Part 1 Multiple Choice

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

Use the photo below to answer questions 1 and 2.



1. The photograph shows the reaction of copper (Cu) with silver nitrate (AgNO_3) to produce copper nitrate ($\text{Cu}(\text{NO}_3)_2$) and silver (Ag). The chemical equation that describes this reaction is the following:



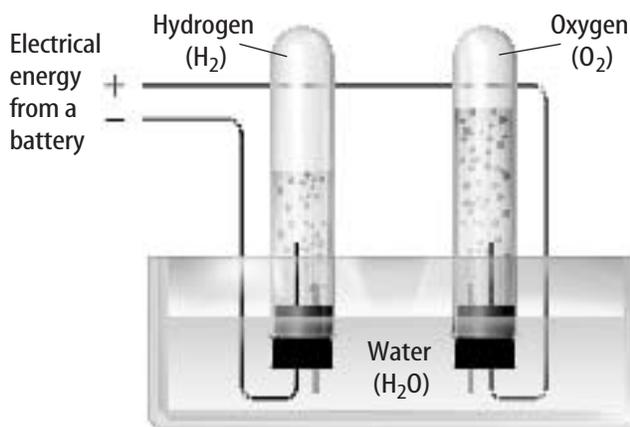
What term describes what is happening in the reaction?

- A. catalyst
B. chemical change
C. inhibitor
D. physical change
2. Which of the following terms describes the copper on the left side of the equation?
A. reactant
B. catalyst
C. enzyme
D. product
3. Which of the following terms best describes a chemical reaction that absorbs heat energy?
A. catalytic
B. exothermic
C. endothermic
D. acidic
4. What should be balanced in a chemical equation?
A. electrons
B. atoms
C. molecules
D. molecules and atoms

Test-Taking Tip

Read All Questions Never skip a question. If you are unsure of an answer, mark your best guess on another sheet of paper and mark the question in your test booklet to remind you to come back to it at the end of the test.

Use the photo below to answer questions 5 and 6.



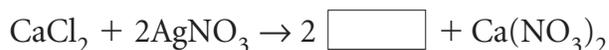
5. The photograph above shows a demonstration of electrolysis, in which water is broken down into hydrogen and oxygen. Which of the following is the best way to write the chemical equation for this process?
A. $\text{H}_2\text{O} + \text{energy} \rightarrow \text{H}_2 + \text{O}_2$
B. $\text{H}_2\text{O} + \text{energy} \rightarrow 2\text{H}_2 + \text{O}_2$
C. $2\text{H}_2\text{O} + \text{energy} \rightarrow 2\text{H}_2 + \text{O}_2$
D. $2\text{H}_2\text{O} + \text{energy} \rightarrow 2\text{H}_2 + 2\text{O}_2$
6. For each atom of hydrogen that is present before the reaction begins, how many atoms of hydrogen are present after the reaction?
A. 1
B. 2
C. 4
D. 8
7. What is the purpose of an inhibitor in a chemical reaction?
A. decrease the shelf life of food
B. increase the surface area
C. decrease the speed of a chemical reaction
D. increase the speed of a chemical reaction

Part 2 Short Response/Grid In

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

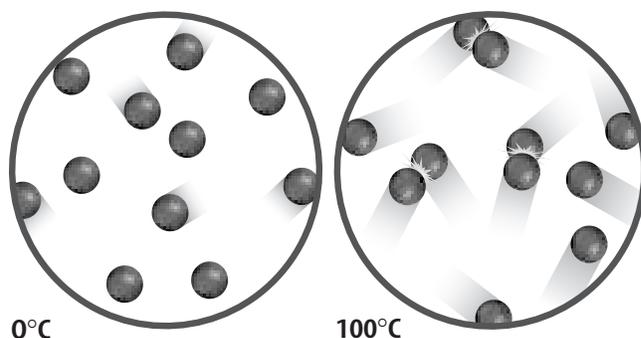
8. Is a change in the volume of a substance a physical or a chemical change? Explain.

Use the equation below to answer question 9.



9. When solutions of calcium chloride (CaCl_2) and silver nitrate (AgNO_3) are mixed, calcium nitrate ($\text{Ca(NO}_3)_2$) and a white precipitate, or residue, form. Determine the chemical formula of the precipitate.

Use the illustration below to answer questions 10 and 11.



10. The figure above demonstrates the movement of water molecules at temperatures of 0°C and 100°C . What would happen to the movement of the molecules if the temperature dropped far below 0°C ?
11. Describe how the difference in the movement of the molecules at two different temperatures affects the rate of most chemical reactions.
12. Is activation energy needed for reactions that release energy? Explain why or why not.

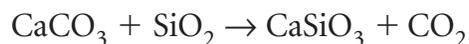
Part 3 Open Ended

Record your answers on a sheet of paper.

Use the illustration below to answer questions 13 and 14.



13. The photograph above shows a forest fire that began when lightning struck a tree. Describe the chemical reaction that occurs when trees burn. Is the reaction endothermic or exothermic? What does this mean? Why does this cause a forest fire to spread?
14. The burning of logs in a forest fire is a chemical reaction. What prevents this chemical reaction from occurring when there is no lightning to start a fire?
15. Explain how the surface area of a material can affect the rate at which the material reacts with other substances. Give an example to support your answer.
16. One of the chemical reactions that occurs in the formation of glass is the combining of calcium carbonate (CaCO_3) and silica (SiO_2) to form calcium silicate (CaSiO_3) and carbon dioxide (CO_2):



Describe this reaction using the names of the chemicals. Discuss which bonds are broken and how atoms are rearranged to form new bonds.