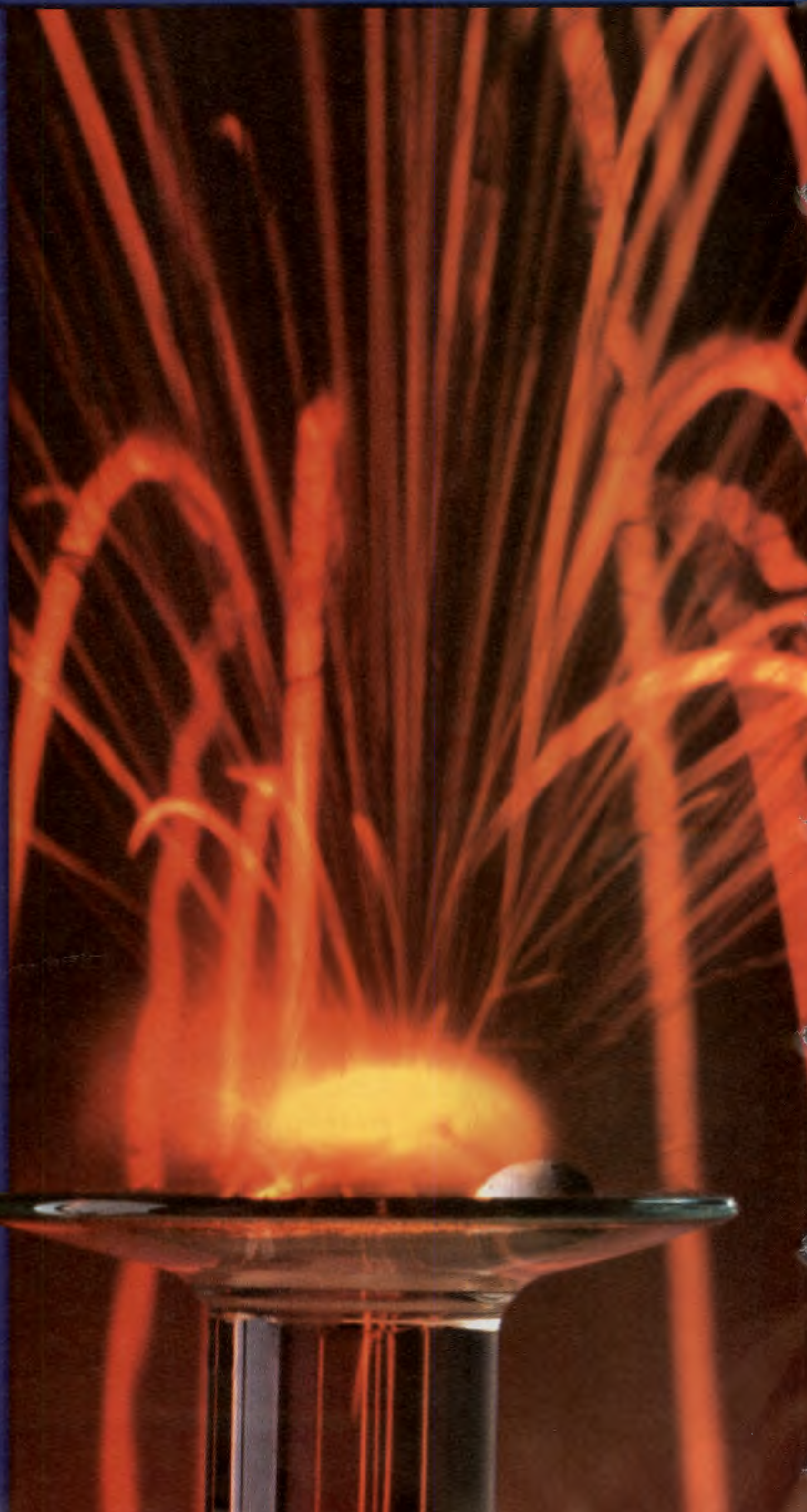
Chapter 6

Chemical Reactions



CALIFORNIA Standards Preview

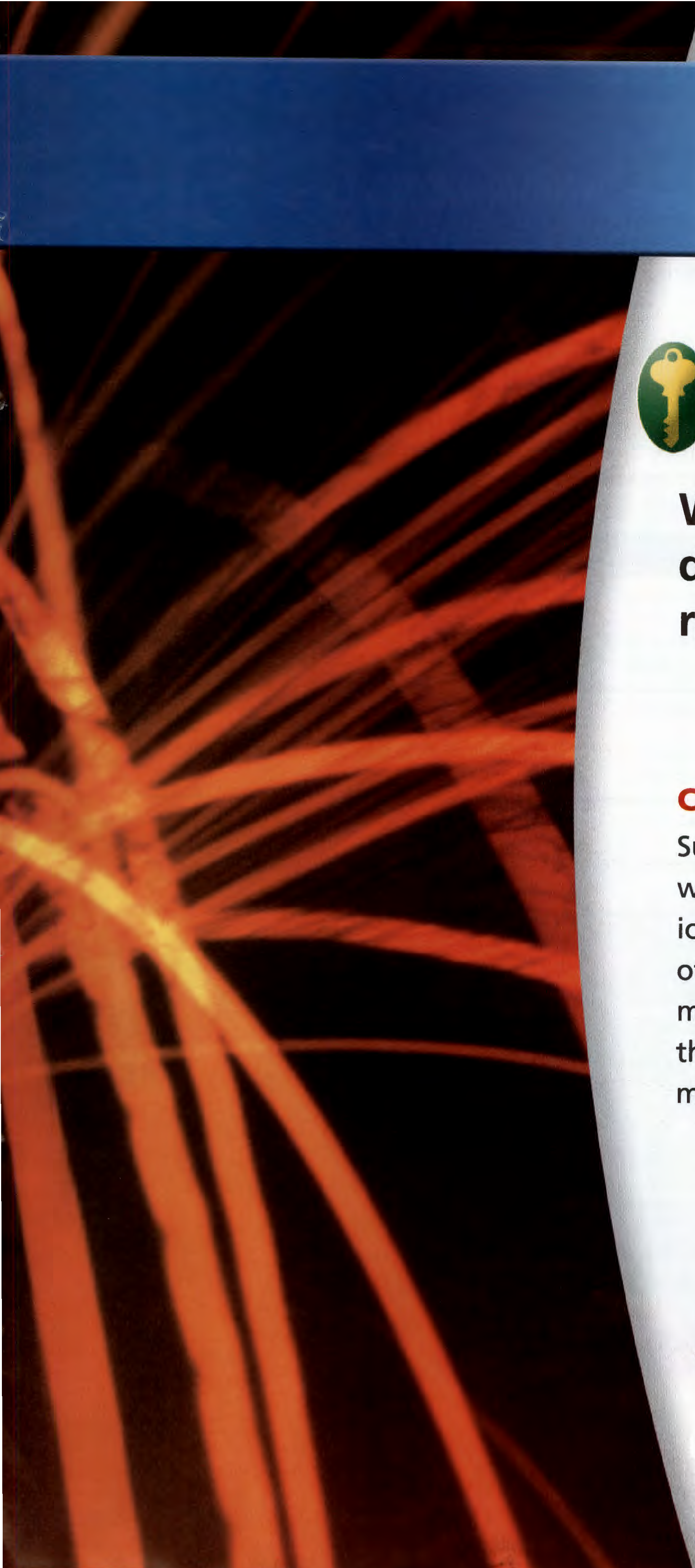
S 8.5 Chemical reactions are processes in which atoms are rearranged into different combinations of molecules. As a basis for understanding this concept:

- **a.** Students know reactant atoms and molecules interact to form products with different chemical properties.
- **b.** Students know the idea of atoms explains the conservation of matter. In chemical reactions the number of atoms stays the same no matter how they are arranged, so their total mass stays the same.
- **c.** Students know chemical reactions usually liberate heat or absorb heat.

S 8.9 Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations. Students will:

- **a.** Plan and conduct a scientific investigation to test a hypothesis.
- **b.** Evaluate the accuracy and reproducibility of data.

Sparks fly as sodium metal reacts with water. ▶



Video Preview

Discovery Channel School

Chemical Reactions

Focus on the

BIG Idea

S 8.5

What happens during a chemical reaction?

Check What You Know

Suppose you fill a sealable bag with ice cubes, and you allow the ice to melt. How would the mass of the bag and ice before melting compare to the mass of the water and the bag after melting? Explain your answer.

Build Science Vocabulary

The images shown here represent some of the key terms in this chapter. You can use this vocabulary skill to help you understand the meaning of some key terms in this chapter.

Vocabulary Skill

Identify Multiple Meanings

Some familiar words have more than one meaning. Words you use everyday may have different meanings in science.

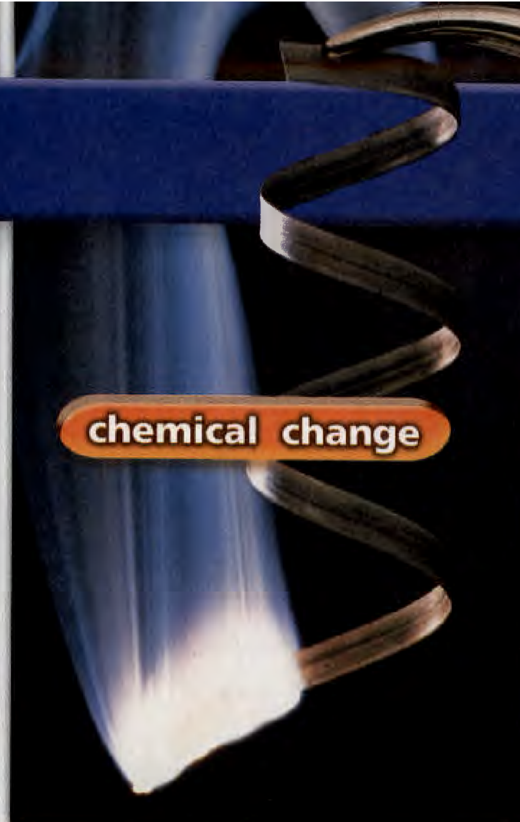
Word	Everyday Meaning	Scientific Meaning
concentration	*n.* Close attention for a long period of time **Example:** Studying with the TV on affects her concentration.	*n.* The amount of a substance in a given volume **Example:** Most soft drinks contain a high concentration of sugar.
matter	*n.* The subject of discussion, concern, or action **Example:** The subject matter of the movie was space travel.	*n.* Anything that has mass and takes up space **Example:** Solids, liquids, and gases are states of matter.
product	*n.* Anything that is made or created **Example:** Milk and cheeses are dairy products.	*n.* A substance formed as a result of a chemical reaction **Example:** In a chemical reaction, substances can combine to form one or more products.

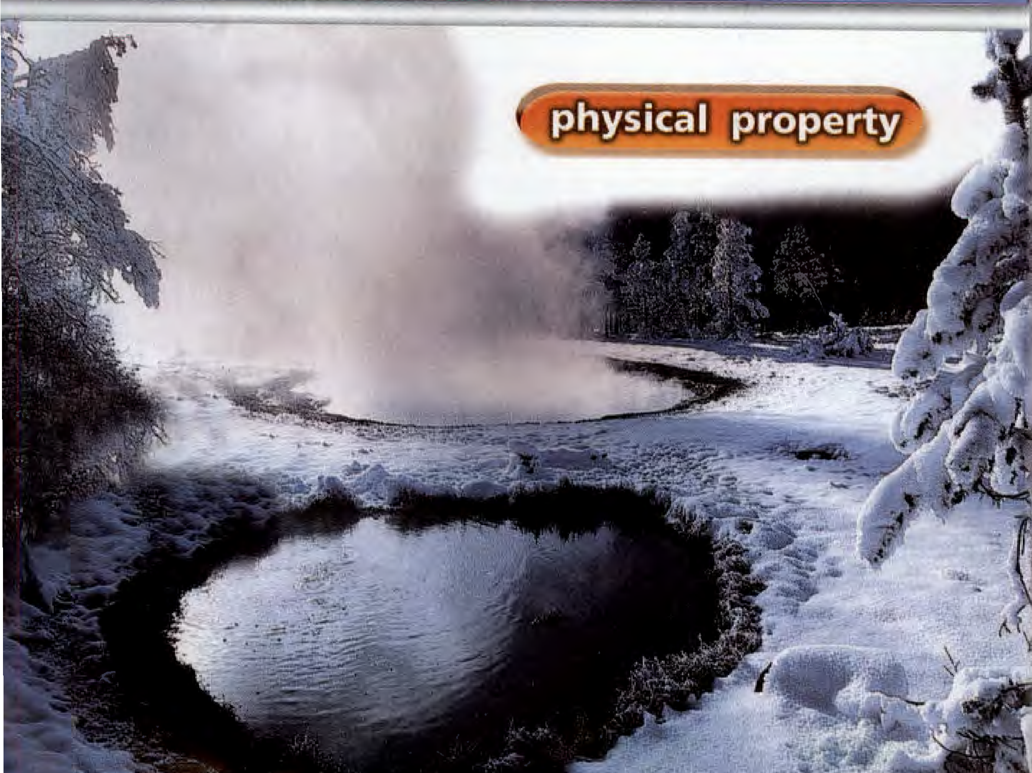
Apply It!

Complete the sentences below with the correct word from the list above. Then identify the terms that have scientific meanings.

1. The coach told the team to keep its __________ during the game.

2. Seawater has a high __________ of salt.





Chapter 6 Vocabulary

Section 1 (page 214)
matter
chemistry
physical property
chemical property
physical change
chemical change
reactant
product
precipitate
endothermic reaction
exothermic reaction

Section 2 (page 224)
chemical equation
conservation of matter
open system
closed system
coefficient
synthesis
decomposition
replacement

Section 3 (page 234)
activation energy
concentration
catalyst
enzyme
inhibitor

Section 4 (page 242)
combustion
fuel

Interactive Textbook
Build Science Vocabulary *Online*
Visit: PHSchool.com
Web Code: cxj-2060

How to Read Science

Reading Skill

Take Notes

Science chapters are packed with information. Each section needs to be read at least twice. After finding the main idea and important details, take notes so you have something to study.

In your notebook, create a two-column note-taking organizer.

- Label the left side "Recall Clues and Questions."
- Label the right side "Notes."
- Under "Notes," write key ideas, using phrases and abbreviations. Include a few important details.
- Use your notes to write a summary statement for each red heading.
- Under "Recall Clues and Questions," write study questions.

As you take notes, think about the key concepts and key terms in the section. Look at the example for Section 1 in this chapter.

Recall Clues & Questions	Notes
What is matter?	Matter: anything that has mass and takes up space
How can matter be described?	Properties of matter • Physical properties—melting point, boiling point, color, hardness • Chemical properties—flammability, ability to rust or tarnish Summary Statement: Matter can be described in terms of physical properties and chemical properties.

Apply It!

What are two important ideas found in the notes above? What questions in the left column help you recall the content?

Take notes as you read each section in this chapter.

Lab zone

Standards Investigation

S 8.5.b

Demonstrate Conservation of Matter

When water evaporates, it is not destroyed or lost. In fact, matter is never created or destroyed in either a physical change or a chemical reaction. In this investigation, you will design and build a closed structure in which a chemical reaction can occur. You will use the chamber to confirm that matter is not created or destroyed in a chemical reaction.

Your Goal

To design and build a closed chamber in which sugar can be broken down

Your structure must

- be made of materials that are approved by your teacher
- be built to specifications agreed upon by the class
- be a closed system so the masses of the reactants and products can be measured
- be built following the safety guidelines in Appendix A

Plan It!

Before you design your reaction chamber, find out how sugar can be broken down. Next, brainstorm with classmates to determine the safety features of your chamber. Then choose materials for your structure and sketch your design. When your teacher has approved your design, build and test your structure.

Section 1

Observing Chemical Change

CALIFORNIA **Standards Focus**

S 8.5.a Students know reactant atoms and molecules interact to form products with different chemical properties.

S 8.5.c Students know chemical reactions usually liberate heat or absorb heat.

How can changes in matter be described?

How can you tell when a chemical reaction occurs?

Key Terms

- matter
- chemistry
- physical property
- chemical property
- physical change
- chemical change
- reactant
- product
- precipitate
- endothermic reaction
- exothermic reaction

Lab zone **Standards Warm-Up**

How Does Matter Change?

1. Put on your safety goggles. Place 2 small spoonfuls of baking soda into a clear plastic cup.
2. Holding the cup over a large bowl or sink, add about 125 mL of vinegar. Swirl the cup gently.
3. Look at the material in the cup. What changes do you see? Feel the outside of the cup. What do you notice about the temperature?
4. Carefully fan the air above the liquid toward you. What do you smell?

Think It Over

Observing What changes did you detect using your senses of smell and touch?

Picture yourself toasting marshmallows over a campfire. You see the burning logs change from hard solids to a soft pile of ash. You hear popping and hissing sounds from the fire as the wood burns. You smell smoke. You feel the heat on your skin. Finally, you taste the results. The crisp brown surface of the toasted marshmallow tastes quite different from the soft white surface of a marshmallow just out of its bag. Firewood, skin, and marshmallows are all examples of matter. **Matter** is anything that has mass and takes up space. The study of matter and how matter changes is called **chemistry.**

Chemical change can lead to a treat. ▶

Matter and Change

Part of chemistry is describing matter. When you describe matter, you explain its characteristics, or properties, and how it changes. Figure 1 lists some of the properties of water. Recall that matter can be described in terms of two kinds of properties—physical properties and chemical properties. **Changes in matter can be described in terms of physical changes and chemical changes.**

Properties of Matter A **physical property** is a characteristic of a substance that can be observed without changing the substance into another substance. The temperature at which a solid melts is a physical property. For example, ice melts at a temperature of zero degrees Celsius. Color, hardness, texture, shine, and flexibility are some other physical properties of matter. The ability of a substance to dissolve in water and how well it conducts heat and electricity are examples of still more physical properties of matter.

A **chemical property** is a characteristic of a substance that describes its ability to change into other substances. To observe the chemical properties of a substance, you must change it to another substance. For example, when magnesium burns, it combines with oxygen in the air, forming a new substance called magnesium oxide. The chemical property of being able to burn in oxygen is called flammability. Other chemical properties include a material's ability to rust or tarnish.

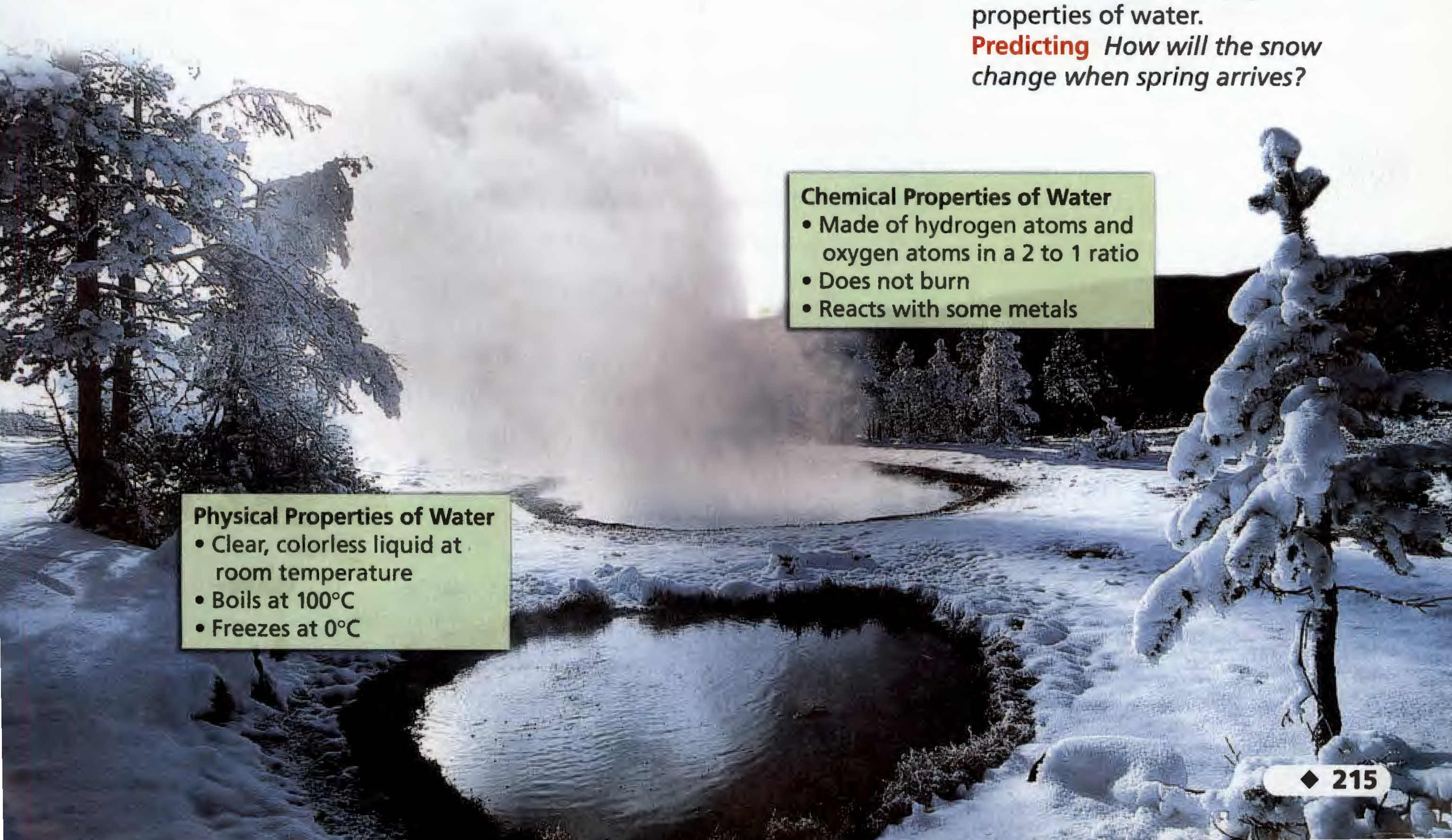


FIGURE 1
Properties of Water
This geyser gives off hot water and water vapor, which condenses into a visible cloud in the cold air. The temperatures at which water boils and freezes are physical properties of water.
Predicting *How will the snow change when spring arrives?*

FIGURE 2
Changes in Matter
Matter can undergo both physical change and chemical change.

Lab zone Try This Activity

Observing Change

1. In a sealable plastic bag, add 10 g of calcium chloride and 10 g of baking soda.
2. Carefully lower a small paper cup containing 30 mL of water into the bag.
3. Squeeze out any excess air from the bag, and then seal it. Make sure that the bag is completely sealed.
4. Tip over the bag so that the water spills out of the cup and mixes with the calcium chloride and baking soda.
5. Record your observations on a sheet of paper.

Inferring Did you observe a physical change or a chemical change? Explain your answer.

Changes of Matter Like properties of matter, changes in matter can be physical or chemical. A **physical change** is any change that alters the form or appearance of a substance but does not make the substance into another substance. For example, when you squash a marshmallow, you cause a physical change. The shape of the marshmallow changes but not the taste. It's still made of the same compounds that have the same properties. In a physical change, one or more physical properties of the material are altered, but the chemical composition remains the same. Bending, crushing, breaking, and cutting are all examples of physical changes. Changes of state, such as melting, freezing, boiling, and condensing, are also physical changes.

Sometimes when matter changes, its chemical composition is changed. For example, the brown crust on a toasted marshmallow is the result of sugar changing to a mixture of different substances called caramel. A change in matter that produces one or more new substances is a **chemical change**, or chemical reaction. In a chemical change, the atoms are rearranged to form new substances with different chemical and physical properties. The substances that undergo change in a chemical reaction are called **reactants**. The new substances formed by the reaction are called **products**.

Bonding and Chemical Change **Chemical changes occur when bonds break and new bonds form.** As a result, new substances are produced. You may recall that atoms form bonds when they share or transfer electrons. The reaction pictured in Figure 3 involves both the breaking of shared bonds and a transfer of electrons.

Oxygen gas (O_2) in the air consists of molecules made of two oxygen atoms that share electrons. These bonds are broken when oxygen reacts with magnesium (Mg). Each magnesium atom transfers two of its electrons to an oxygen atom. The oxygen atom becomes a negative ion, and the magnesium atom becomes a positive ion. Recall that oppositely charged ions attract. An ionic bond forms between the Mg^{2+} ions and the O^{2-} ions. The ionic compound magnesium oxide (MgO) is produced, and energy is released. Magnesium oxide—a white, crumbly powder—has properties that differ from those of either shiny magnesium or oxygen gas. For example, while magnesium melts at about 650°C, it takes temperatures of more than 2,800°C to melt magnesium oxide.

Reading Checkpoint **What are two properties of magnesium oxide?**

Go Online SCILINKS NSTA
For: Links on chemical changes
Visit: www.SciLinks.org
Web Code: scn-1221

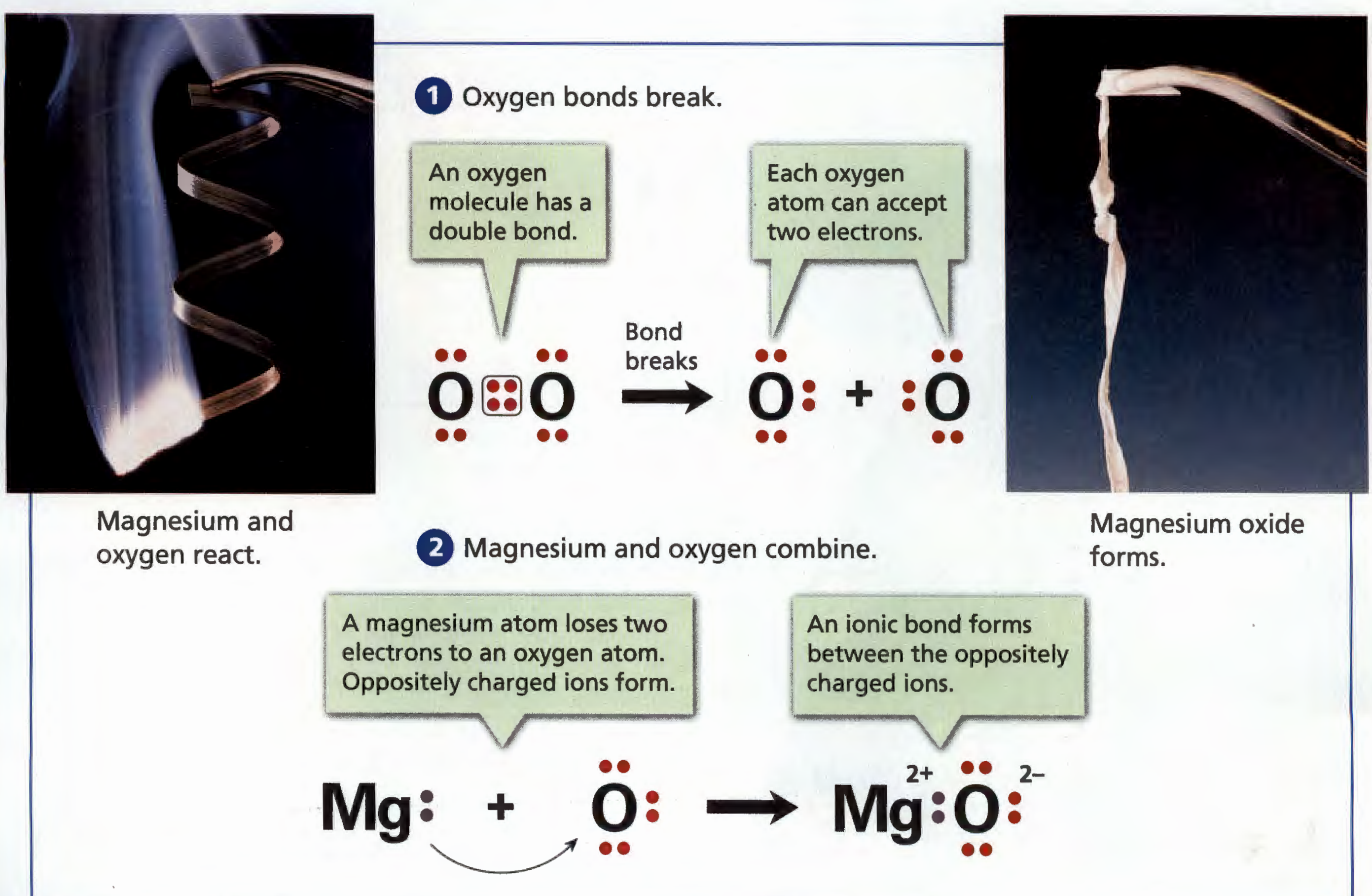


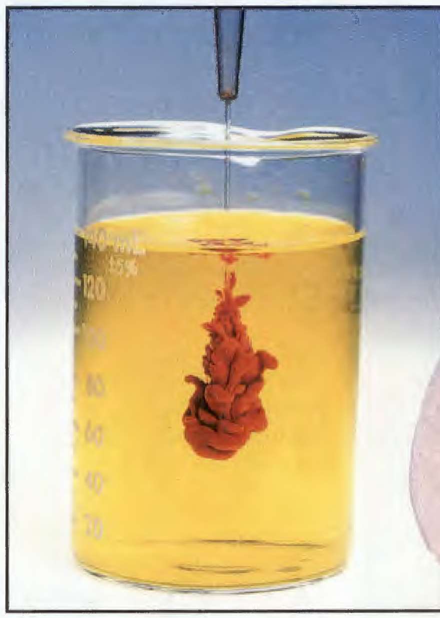
FIGURE 3
Bonding and Chemical Change
As magnesium burns, bonds between atoms break and new bonds form. The reaction gives off energy. **Interpreting Diagrams** *Why does the oxygen ion have a 2– charge?*

Evidence for Chemical Reactions

How can you tell when a chemical reaction occurs? You need to look for clues. **Chemical reactions involve changes in properties and changes in energy that you can observe.**

Changes in Properties One way to detect chemical reactions is to observe changes in the properties of the materials involved. Changes in properties result when new substances form. Figure 4 shows some examples. For instance, a color change may signal that a new substance has formed. Or, the mixing of two solutions may yield a precipitate. A **precipitate** (pree SIP uh tayt) is a solid that forms from solution during a chemical reaction. Another observable change is the formation of a gas from solid or liquid reactants. Physical properties such as texture and hardness may also change. For example, moist bread dough forms a dry, porous solid after baking.

FIGURE 4
Evidence for Chemical Reactions
Many kinds of change provide evidence that a chemical reaction has occurred.
Applying Concepts *What other evidence might tell you a chemical reaction has occurred?*



Two clear liquids react, ▲ forming a precipitate.

◀ The light green leaves of early spring slowly turn darker as chemical reactions in the leaves produce more of the green compound chlorophyll.

Changes in physical properties can be easy to spot as reactants change into products. But what about the chemical properties? Reactant atoms and molecules interact to form products with different chemical properties. For example, sodium (Na) and chlorine (Cl) react to form an ionic compound, sodium chloride (NaCl). Both reactants are very reactive elements. However, the product, sodium chloride, is a very stable compound.

Although you may observe a property change in matter, the change does not always indicate that a chemical reaction has taken place. Sometimes physical changes give similar results. For example, when water boils, the gas bubbles you see are made of molecules of water, just as the original liquid was. The sign of a chemical reaction is that one or more new substances are produced. For example, when an electric current is passed through water during electrolysis, two new substances are produced, hydrogen gas (H_2) and oxygen gas (O_2).

Reading Checkpoint **How is a precipitate evidence for a chemical reaction?**

Lab zone Try This **Activity**

Mostly Cloudy

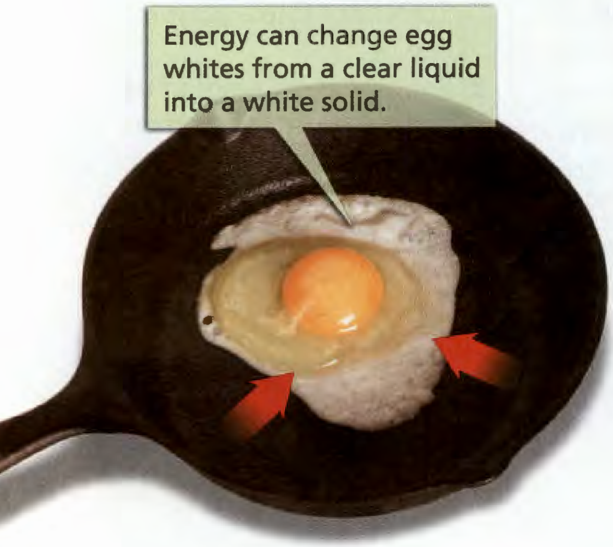
1. Put on your safety goggles and apron.
2. Pour about 5 mL of limewater into a plastic cup.
3. Pour an equal amount of plain water into another plastic cup.
4. Add about 5 mL of carbonated water to each of the cups.

Drawing Conclusions In which cup do you think a chemical reaction occurred? What evidence supports your conclusion?

A golden loaf of bread with its crunchy crust has very different properties from the soft dough that went into the oven. ▼

Oxygen bubbles that form during photosynthesis collect on the leaves of a plant. ▼

FIGURE 5
Endothermic Reactions
When you fry an egg, it absorbs energy. The reactions that occur are endothermic.
Interpreting Photos *What properties of the egg change as it cooks?*



Changes in Energy As matter changes, it can either absorb or release energy. Chemical reactions usually absorb heat or liberate heat. One common indication of a change in energy is a change in temperature. If you did the Standards Warm-Up activity, you observed that the mixture became colder. When baking soda (sodium bicarbonate) reacts with vinegar, the reaction absorbs heat from the solution, making it feel colder.

Recall that a chemical reaction occurs when bonds break and new bonds form. Breaking bonds between atoms requires energy. Making a bond releases energy. In an **endothermic reaction** (en doh THUR mik), the total making and breaking of bonds results in a net absorption of energy. The energy is absorbed as heat from nearby matter, which cools.

The reaction of baking soda and vinegar is endothermic. During the reaction, energy is absorbed, causing the surroundings to become cooler. However, endothermic reactions do not always result in a decrease in temperature. Many endothermic reactions occur only when heat is constantly added. For example, the reactions that occur when you fry an egg are endothermic.

Reviewing Math: Algebra and Functions 7.1.5

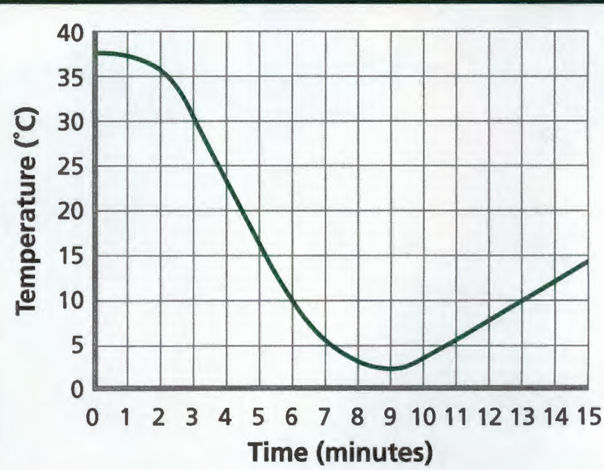
Math Analyzing Data

Energy in Chemical Changes

A student places two substances in a flask and measures the temperature once per minute while the substances react. The student plots the time and temperature data and creates the graph at right.

1. **Reading Graphs** What was the temperature in the flask at 3 minutes? When was the first time the temperature was 6°C?
2. **Calculating** How many degrees did the temperature drop between 2 minutes and 5 minutes?
3. **Interpreting Data** Is the reaction endothermic or exothermic? Explain.
4. **Inferring** At what temperature did the reaction stop? How can you tell?

Energy of a Chemical Reaction



5. **Drawing Conclusions** Suppose the temperature in the flask increased instead of decreased as the reaction occurred. In terms of energy, what kind of reaction would it be? Explain.

FIGURE 6
An Exothermic Reaction
Enough energy is released by the burning of airplane fuel to keep a plane moving fast enough to fly.

In an **exothermic reaction** (ek soh THUR mik), the total making and breaking of bonds results in a net release of energy. The energy is typically released as heat into nearby matter. For example, the reaction between fuel and oxygen in an airplane engine releases energy, mostly in the form of heat. The heat causes gases in the engine to expand. The expansion and movement of the gases out of the plane exert a force that moves the plane forward.

Reading Checkpoint **What is an endothermic reaction?**

Section 1 Assessment

S 8.5.a, 8.5.c, E-LA: Reading 8.1.0, Writing 8.2.4

Vocabulary Skill **Identify Multiple Meanings** Review the two meanings of the word *matter.* Then use the scientific meaning in a sentence.

Reviewing Key Concepts

1. a. **Explaining** What is the difference between the physical properties and the chemical properties of a substance?
   b. **Posing Questions** When silver coins are found in ancient shipwrecks, they are coated with a black crust. What question could you ask to help you decide whether the silver underwent a chemical change or a physical change? Explain.
   c. **Making Generalizations** In terms of chemical bonds and electrons, what kinds of changes occur between atoms when substances undergo chemical reactions?
2. a. **Listing** What kinds of evidence can you use to determine if a chemical reaction has occurred?
   b. **Interpreting Photographs** How do the properties of the cooked egg shown in Figure 5 differ from the properties of a raw egg?
   c. **Comparing and Contrasting** How are endothermic and exothermic reactions the same? How are they different?

Writing in Science

Persuasive Letter Imagine you have a pen pal who is studying chemistry just like you are. Your pen pal claims the change from liquid water to water vapor is a chemical change. Write a brief letter that might convince your pen pal otherwise.

Lab zone **Skills Lab**

Where's the Evidence?

S 8.5.a, 8.9.b

Problem

What are some signs that a chemical reaction has taken place?

Skills Focus

observing, predicting, drawing conclusions

Materials

- 4 small plastic cups
- birthday candles
- 2 plastic spoons
- sugar
- tongs
- clay
- matches
- sodium carbonate (powdered solid)
- graduated cylinder, 10 mL
- aluminum foil, about 10-cm square
- dilute hydrochloric acid in a dropper bottle
- copper sulfate solution
- sodium carbonate solution

Procedure

Preview the steps for each reaction and copy the data table into your notebook.

PART 1

1. Put a pea-sized pile of sodium carbonate into a clean plastic cup. Record in the data table the appearance of the sodium carbonate.
2. Observe a dropper containing hydrochloric acid. Record the appearance of the acid. **CAUTION:** *Hydrochloric acid can burn you or anything else it touches. Wash spills immediately with water.*
3. Make a prediction about how you think the acid and the sodium carbonate will react when mixed. Record your prediction.
4. Add about 10 drops of hydrochloric acid to the sodium carbonate. Swirl to mix the contents of the cup. Record your observations.

PART 2

5. Fold up the sides of the aluminum foil square to make a small tray.
6. Use a plastic spoon to place a pea-sized pile of sugar into the tray.
7. Carefully describe the appearance of the sugar in your data table.

Data Table

Reaction	Observations Before Reaction	Predictions	Observations During Reaction	Observations After Reaction
1. Sodium carbonate (powder) + hydrochloric acid				
2. Sugar + heat				
3. Copper sulfate + sodium carbonate solutions				

8. Secure a small candle on your desktop in a lump of clay. Carefully light the candle with a match only after being instructed to do so by your teacher. **CAUTION:** *Tie back long hair and loose clothing.*
9. Predict what you think will happen if you heat the sugar. Record your prediction.
10. Use tongs to hold the aluminum tray. Heat the sugar slowly by moving the tray gently back and forth over the flame. Make observations while the sugar is heating.
11. When you think there is no longer a chemical reaction occurring, blow out the candle.
12. Allow the tray to cool for a few seconds and set it down on your desk. Record your observations of the material left in the tray.

PART 3

13. Put about 2 mL of copper sulfate solution in one cup. **CAUTION:** *Copper sulfate is poisonous and can stain your skin and clothes. Do not touch it or get it in your mouth.* Put an equal amount of sodium carbonate solution in another cup. Record the appearance of both liquids.
14. Write a prediction of what you think will happen when the two solutions are mixed.
15. Combine the two solutions and record your observations. **CAUTION:** *Dispose of the solutions as directed by your teacher.*
16. Wash your hands when you have finished working.

Analyze and Conclude

1. **Predicting** How do the results of each reaction compare with your predictions?
2. **Observing** How did you know when the reaction in Part 1 was over?
3. **Interpreting Data** What was the evidence of a chemical reaction in Part 1? In Part 2?
4. **Observing** Was the product of the reaction in Part 3 a solid, a liquid, or a gas? How do you know?
5. **Drawing Conclusions** How do you know if new substances were formed in each reaction?
6. **Communicating** Make a table or chart briefly describing each chemical change in this lab, followed by the evidence for the chemical change.

More to Explore

Keep your data table handy as you read the rest of this chapter. As you learn more about chemical reactions, try to identify the products that formed in Parts 1, 2, and 3 of the Skills Lab. Research the physical properties of each product by using your library or the Internet. Evaluate the accuracy of your data by comparing the properties of the substances produced in the lab to the properties that you found in your research.

Section 2

Describing Chemical Reactions

CALIFORNIA Standards Focus

S 8.5.b Students know the idea of atoms explains the conservation of matter. In chemical reactions the number of atoms stays the same no matter how they are arranged, so their total mass stays the same.

- What information does a chemical equation contain?
- How is matter conserved during a chemical reaction?
- What must a balanced chemical equation show?
- What are three types of chemical reactions?

Key Terms

- chemical equation
- conservation of matter
- open system
- closed system
- coefficient
- synthesis
- decomposition
- replacement

Lab zone Standards Warm-Up

Do You Lose Anything?

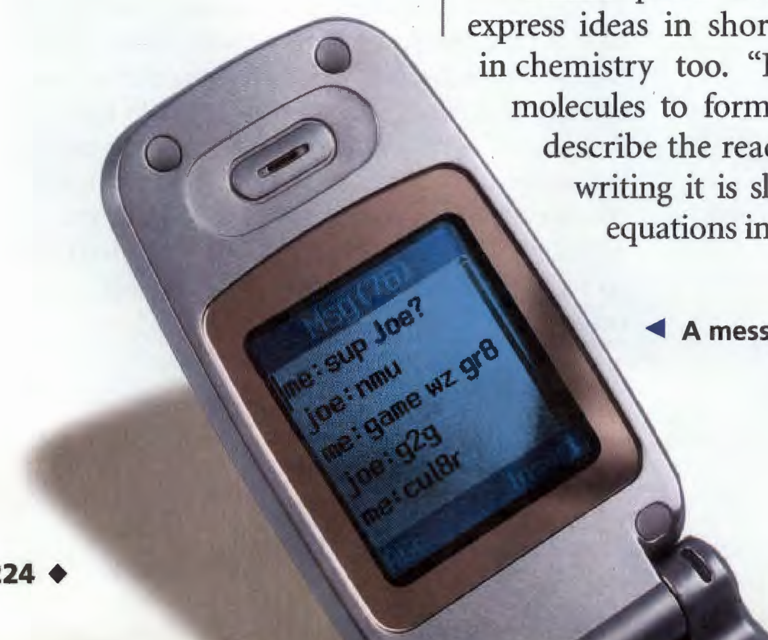
1. Place about two dozen coins on a table. Sort them into stacks of pennies, nickels, dimes, and quarters.
2. Count and record the number of coins in each stack. Calculate and record the value of each stack and the total of all stacks combined.
3. Mix all the coins together and then divide them randomly into four unsorted stacks.
4. Again calculate the value of each stack and the total amount of money. Count the total number of each type of coin.
5. Repeat Steps 3 and 4.

Think It Over

Making Models What happened to the total value and types of coins when you rearranged them? Did rearranging the coins change the properties of any coin? If you think of the coins as each representing a different type of atom, what does this model tell you about chemical reactions?

You look at your cellular phone display and read the message "U wan2 gt pza 2nite?" You reply "No. MaB TPM. CUL8R." These messages are short for saying "Do you want to get some pizza tonight?" and "No. Maybe tomorrow afternoon (P.M.). See you later."

Cellular phone messages use symbols and abbreviations to express ideas in shorter form. A type of shorthand is used in chemistry too. "Hydrogen molecules react with oxygen molecules to form water molecules" is a lengthy way to describe the reaction between hydrogen and oxygen. And writing it is slow. Instead, chemists often use chemical equations in place of words.



◄ A message on a cellular display

What Are Chemical Equations?

A **chemical equation** is a short, easy way to show a chemical reaction, using symbols instead of words. Although chemical equations are shorter than sentences, they contain more information. **Chemical equations use chemical formulas and other symbols instead of words to summarize a reaction.**

Using Formulas All chemical equations use formulas to represent the substances involved in a reaction. You may recall that a chemical formula is a combination of symbols that represent the elements in a compound. For example, CO_2 is the formula for carbon dioxide. The formula tells you that the ratio of carbon to oxygen is 1 to 2. Carbon dioxide is a molecular compound, so it is made up of molecules. Each carbon dioxide molecule has 1 carbon atom and 2 oxygen atoms. Figure 7 lists formulas of other compounds that may be familiar to you.

Structure of an Equation All chemical equations have a common structure. A chemical equation tells you the substances you start with in a reaction and the substances you get at the end. The substances you have at the beginning are the reactants. When the reaction is complete, you have new substances called products.

The formulas for the reactants are written on the left, followed by an arrow. You read the arrow as "yields." The formulas for the products are written on the right. When there are two or more reactants, they are separated by plus signs. In a similar way, plus signs are used to separate two or more products. Below is the general plan for a chemical equation.

$$\text{Reactant} + \text{Reactant} \longrightarrow \text{Product} + \text{Product}$$

The number of reactants and products can vary. Some reactions have only one reactant or product. Other reactions have two, three, or more reactants or products. In Figure 8, you can see the equation for a reaction that occurs when limestone ($CaCO_3$) is heated. Count the number of reactants and products, and familiarize yourself with the parts of the equation.

FIGURE 7
The formula of a compound identifies the elements in the compound and the ratios in which their atoms are present.

Formulas of Familiar Compounds

Compound	Formula
Water	H_2O
Carbon dioxide	CO_2
Methane	CH_4
Propane	C_3H_8
Sugar (sucrose)	$C_{12}H_{22}O_{11}$
Rubbing alcohol	C_3H_8O
Ammonia	NH_3
Sodium chloride	$NaCl$
Baking soda	$NaHCO_3$

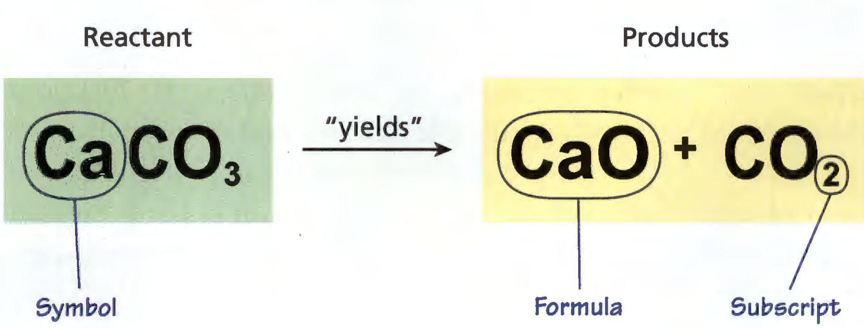


FIGURE 8
A Chemical Equation
Like a building, a chemical equation has a basic structure.
Interpreting Diagrams *What does the subscript 3 in the formula for calcium carbonate tell you?*

Fe	+	S	→	FeS
Iron		Sulfur		Iron Sulfide

FIGURE 9
Conservation of Matter
Matter is conserved in chemical reactions.

Lab zone Try This **Activity**

Is Matter Conserved?

1. Add water to a small, plastic sealable container until it is one-third full.
2. Measure the combined mass of the partially filled container, its screw-on cap, and one quarter of an effervescent tablet.
3. Drop the tablet into the water, and immediately screw on the cap.
4. After the fizzing stops, measure the mass of the sealed container.
5. Slowly remove the cap to release built-up pressure. Measure the combined mass of the unsealed container, its contents, and the cap.

Interpreting Data How did the mass measured in Step 2 compare to the masses measured in Steps 4 and 5? Was matter conserved?

Conservation of Matter

Look closely at the values for mass in Figure 9. Iron and sulfur can react to form iron sulfide. The photograph represents a principle first demonstrated by the French chemist Antoine Lavoisier in 1774. This principle is called **conservation of matter**. It states that, during a chemical reaction, matter is neither created nor destroyed. The total mass of the reactants must equal the total mass of the products.

Conservation of Atoms The idea of atoms explains the conservation of matter. **In chemical reactions, the number of atoms stays the same no matter how they are arranged. So, their total mass stays the same.** Look again at Figure 9. Suppose one atom of iron reacts with one atom of sulfur. At the end of the reaction, you have one iron atom bonded to one sulfur atom in the compound FeS. All the atoms present at the start of the reaction are present at the end of the reaction. The amount of matter does not change. The total mass stays the same before and after the reaction.

Open and Closed Systems At first glance, some reactions may seem to violate the principle of conservation of matter. It's not always easy to measure all the matter involved in a reaction. For example, if you burn a match, oxygen comes from the surrounding air. But how much? Likewise, the products escape into the air. Again, how much?

A burning match is an example of an open system. In an **open system**, matter can enter from or escape to the surroundings. The burned out fire in Figure 10 is another example of an open system. If you want to measure all the matter before and after a reaction, you have to be able to contain it. In a **closed system**, matter is not allowed to enter or leave. The pear decaying under glass in Figure 10 is a closed system. So is a chemical reaction inside a sealed plastic bag.

Reading Checkpoint **What is a closed system?**

FIGURE 10
Open and Closed Systems

A wood fire is an open system because gases escape into the air. A pear in a glass dome is a closed system because the reactants and products are contained inside the dome.
Problem Solving *What masses would you need to measure before and after a wood fire to show conservation of mass?*

Open System
Except for the ash, products of the wood fire have escaped up the chimney or into the room.

Closed System
The total mass of the pear and the substances produced during its decay are contained by the glass dome.

Fresh pear

Decayed pear

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Balancing Chemical Equations

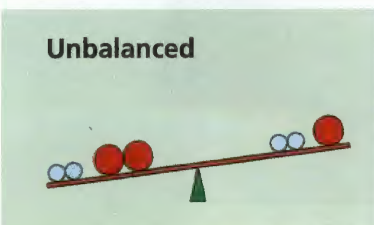
The principle of conservation of matter means that the total number of atoms of each element in the reactants must equal the total number of atoms of each element in the products. **To describe a reaction accurately, a chemical equation must show the same number of each type of atom on both sides of the equation.** Chemists say an equation is balanced when it accurately represents conservation of matter. How can you write a balanced chemical equation?

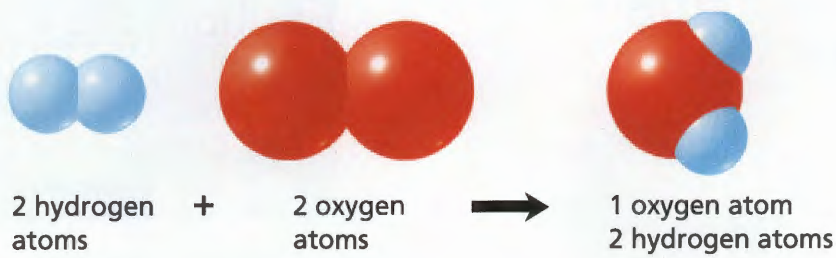
1 Write the Equation Suppose you want to write a balanced chemical equation for the reaction between hydrogen and oxygen that forms water. To begin, write the correct formulas for both reactants and product. Place the reactants, H_2 and O_2, on the left side of the arrow, separated by a plus sign. Then write the product, H_2O, on the right side of the arrow.

$$H_2 + O_2 \longrightarrow H_2O$$

Reactants — Products

2 Count the Atoms Count the number of atoms of each element on each side of the equation. You find two atoms of oxygen in the reactants but only one atom of oxygen in the product.





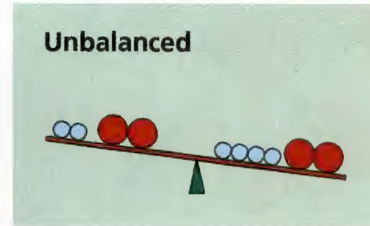
How can you get the number of oxygen atoms on both sides to be the same? You cannot change the formula for water to H_2O_2 because H_2O_2 is the formula for hydrogen peroxide, a different compound. So, how can you show that mass is conserved?

3 Use Coefficients to Balance Atoms To balance the equation, you can change the coefficients. A **coefficient** (koh uh FISH unt) is a number placed in front of a chemical formula in an equation. It tells you the relative amount of a reactant or a product that takes part in the reaction. In the unbalanced equation written in Step 1, the coefficients are understood to be 1.

You can balance the number of oxygen atoms by changing the coefficient of H_2O to 2. Now the right side of the equation has two water molecules, each containing an oxygen atom.

$$H_2 + O_2 \longrightarrow 2\,H_2O$$

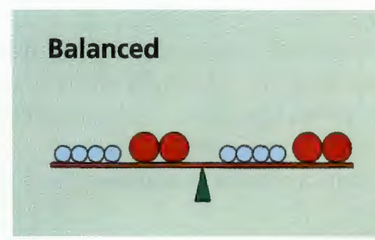
2 hydrogen atoms + 2 oxygen atoms ⟶ 2 oxygen atoms, 4 hydrogen atoms



By balancing the oxygen, you "unbalanced" the number of hydrogen atoms. There are now two hydrogen atoms in the reactants and four in the product. To balance the hydrogen, change the coefficient of H_2 to 2. All the atoms in the reactants are now accounted for in the products.

$$2\,H_2 + O_2 \longrightarrow 2\,H_2O$$

4 hydrogen atoms + 2 oxygen atoms ⟶ 2 oxygen atoms, 4 hydrogen atoms



4 Look Back and Check The equation tells you that two hydrogen molecules react with one oxygen molecule to yield two water molecules. The total number of atoms stays the same before and after the reaction. The equation is balanced.

Reviewing Math: Mathematical Reasoning 7.2.6

Math Analyzing Data

Balancing Chemical Equations

Magnesium (Mg) reacts with oxygen gas (O_2), forming magnesium oxide (MgO). Write a balanced equation for this reaction by following Steps 1 through 4 described above.

1. **Balancing Chemical Equations** Balance the equation for the reaction of sodium metal (Na) with oxygen gas (O_2), forming sodium oxide (Na_2O).
2. **Balancing Chemical Equations** Balance the equation for the reaction of tin (Sn) with chlorine gas (Cl_2), forming tin chloride ($SnCl_2$).

Balancing Equations

1 Write the Equation

$Mg + O_2 \longrightarrow MgO$

2 Count the Atoms

$Mg + O_2 \longrightarrow MgO$

1 2 1 1

3 Use Coefficients to Balance the Atoms

$Mg + O_2 \longrightarrow 2\,MgO$

2 2

$2\,Mg + O_2 \longrightarrow 2\,MgO$

2 2 2 2

4 Look Back and Check

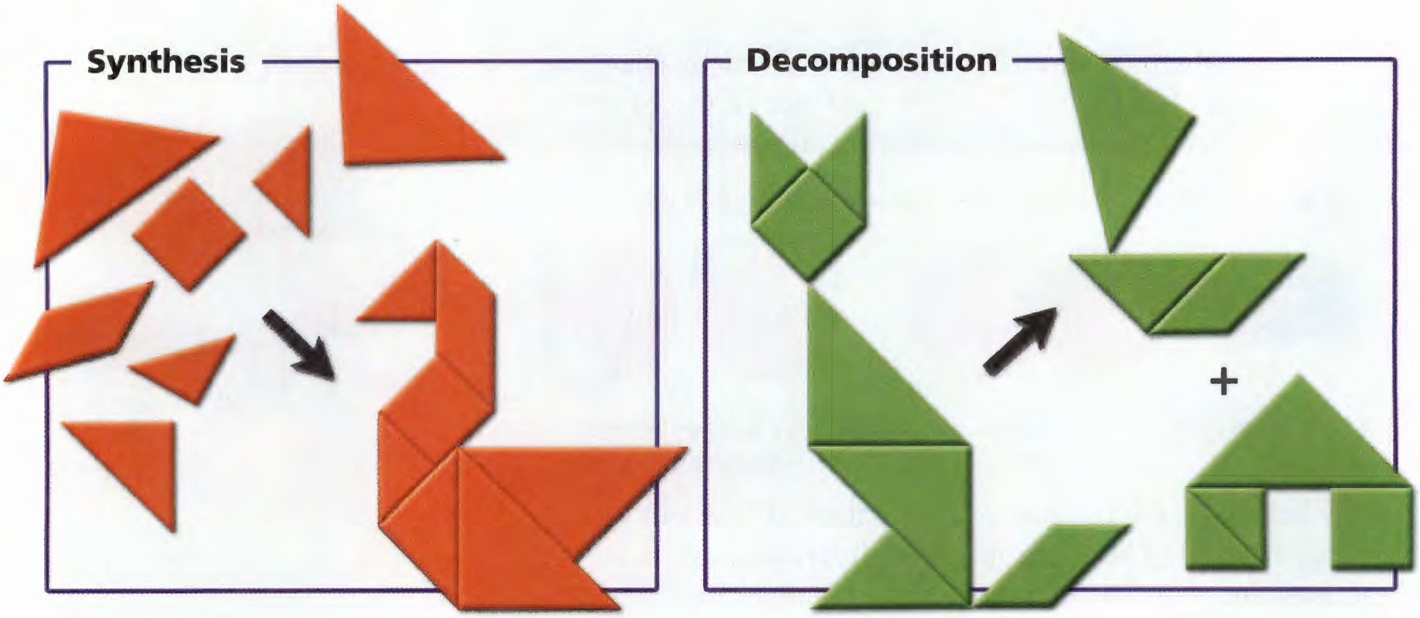


FIGURE 11
Types of Reactions
Three categories of chemical reactions are synthesis, decomposition, and replacement. **Making Models** *How do these different geometric shapes act as models for elements and compounds in reactions?*

Classifying Chemical Reactions

You have already learned how to classify physical changes such as melting, boiling, and freezing. You can classify chemical changes, too. **Three general types of chemical reactions are synthesis, decomposition, and replacement.**

Synthesis Have you ever listened to music from a synthesizer? You can hear many different notes and types of sounds combined to make music. To synthesize is to put things together. In chemistry, when two or more elements or compounds combine to make a more complex substance, the reaction is classified as a **synthesis** (SIN thuh sis). The reaction of hydrogen and oxygen to make water is a synthesis reaction.

Decomposition In contrast to synthesis, **decomposition** occurs when compounds break down into simpler products. You may have a bottle of hydrogen peroxide (H_2O_2) in your house to clean cuts. If you keep such a bottle for a very long time, the hydrogen peroxide decomposes into water and oxygen gas.

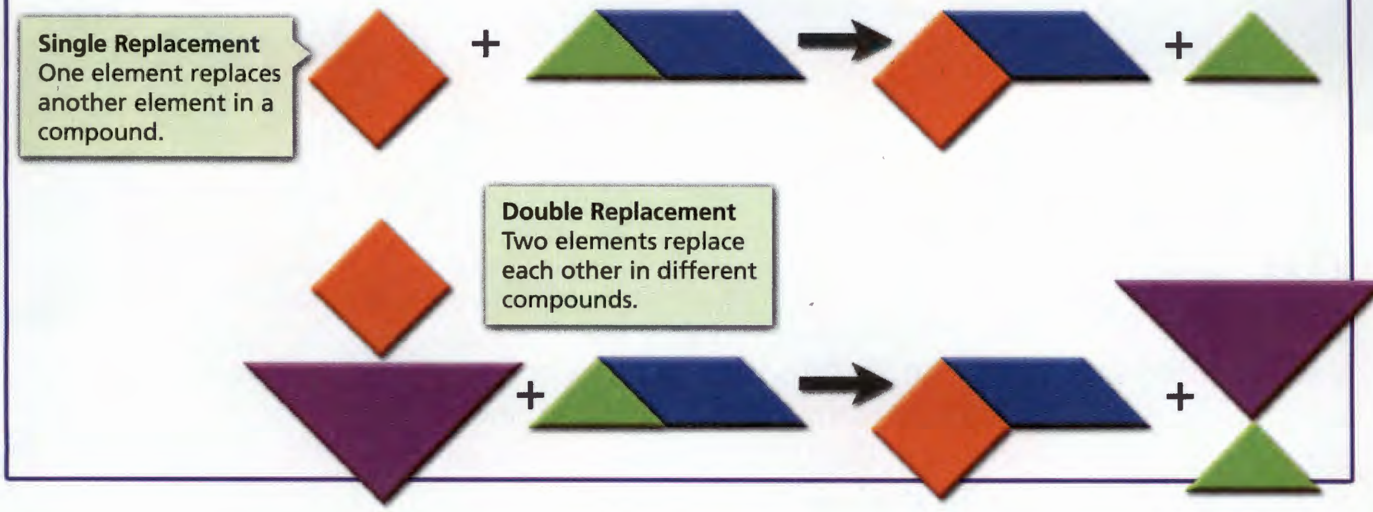
$$2\,H_2O_2 \longrightarrow 2\,H_2O + O_2$$

Replacement When one element replaces another in a compound, or when two elements in different compounds trade places, the reaction is classified as a **replacement**. Look at this example:

$$2\,Cu_2O + C \longrightarrow 4\,Cu + CO_2$$

Copper metal can be obtained by heating copper oxide with carbon. The carbon takes the place of copper.

Replacement



The reaction between copper oxide and carbon is called a *single* replacement reaction because one element, carbon, replaces another element, copper, in the compound. In a *double* replacement reaction, elements in one compound appear to "trade places" with elements in another compound. The following reaction is an example of a double replacement:

$$FeS + 2\ HCl \longrightarrow FeCl_2 + H_2S$$

Use Figure 11 to help you track what happens to elements in different types of chemical reactions.

Section 2 Assessment

S 8.5.b, E-LA: Reading 8.1.0, Math: 7MR2.6

Vocabulary Skill **Identify Multiple Meanings** Review the multiple meaning words. The substance produced in a chemical reaction is called a _____.

Reviewing Key Concepts

1. a. **Identifying** What do the formulas, arrow, and plus signs in a chemical equation tell you?
   b. **Comparing and Contrasting** How are reactants and products treated the same in a chemical reaction? How are they treated differently?
2. a. **Explaining** How does the idea of atoms explain the principle of conservation of matter?
   b. **Applying Concepts** If the total mass of the products of a reaction is 250 g, what was the total mass of the reactants?
3. a. **Reviewing** What are three types of chemical reactions?
   b. **Inferring** What is the smallest possible number of products in a decomposition reaction?
   c. **Classifying** Classify the following reaction:

$$P_4O_{10} + 6\ H_2O \longrightarrow 4\ H_3PO_4$$

Math Practice

Balance the following equations:

4. $Fe_2O_3 + C \longrightarrow Fe + CO_2$
5. $SO_2 + O_2 \longrightarrow SO_3$

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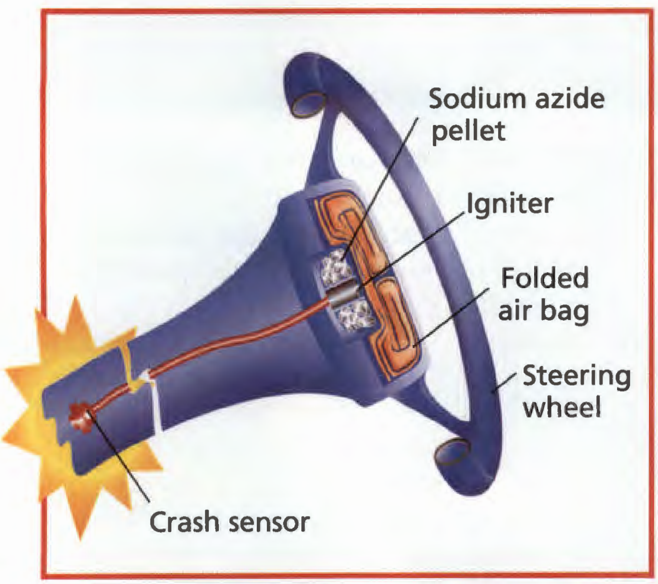
S 8.5.a

Air Bags

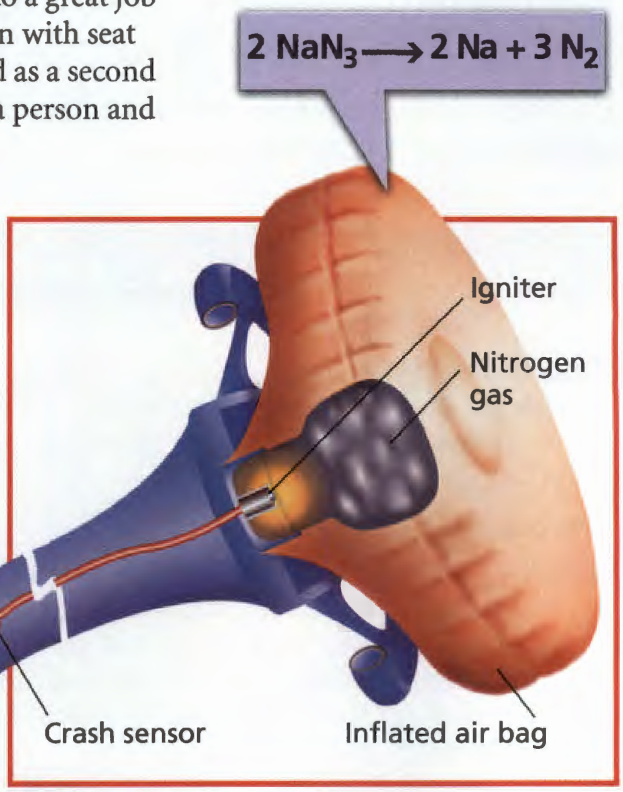
What moves faster than 300 km/h, inflates in less than a second, and saves lives? An air bag, of course! When a moving car is suddenly stopped in a crash, objects inside the car keep moving forward. Death or serious injury can result when passengers hit the hard parts of the car's interior. Air bags, working with seat belts, can slow or stop a person's forward motion in a crash.

How Do Air Bags Increase Safety?

Before front air bags became a requirement in the 1990s, seat belts were the only restraints for passengers in cars. Seat belts do a great job of keeping people from flying forward in a crash, but even with seat belts, some movement takes place. Air bags were designed as a second form of protection. They provide a buffer zone between a person and the steering wheel, dashboard, or windshield.



Collision Detected
The crash sensor is located toward the front of the car. The sensor detects an impact and sends a signal to the air bag igniter to start the chemical reaction.



Air Bag Inflates
Pellets of a compound called sodium azide (NaN_3) are heated, causing a rapid decomposition reaction. This reaction releases sodium metal (Na) and nitrogen gas (N_2). The nitrogen inflates the air bag in about 30 milliseconds.

▲ Car manufacturers must test their vehicles to verify that they meet minimum government safety standards. New cars are required to have air bags on both the driver and passenger sides.

Cushion or Curse?

Air bags save hundreds of lives each year. However, if your body is too close to the air bag when it inflates, the impact of the expanding bag may do more harm than good. Since 1990, more than 200 people, including 140 children, have been killed by air bags inflating close to them. Air bags are designed for adults but pose a risk to smaller, lightweight adults and children. That is why children should never ride in a front seat. They are safer in the back seat without air bags than in the front seat with air bags.

Air Bag Deflates
Tiny holes in the fabric of the air bag allow some of the nitrogen gas to escape, so the bag starts to deflate by the time a person makes contact with it. In this way, the air bag provides a deflating cushion that slows forward movement.

Weigh the Impact

1. Identify the Need
Air bags are called supplemental restraint systems. Why is it so important to restrain people in a collision?

2. Research
Use the Internet to learn how air bags are being changed, added, and redesigned to improve their safety and effectiveness.

3. Write
Choose one type of new air bag technology and summarize it in a few short paragraphs.

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Section 3

Controlling Chemical Reactions

CALIFORNIA Standards Focus

S 8.5.a Students know reactant atoms and molecules interact to form products with different chemical properties.

S 8.5.c Students know chemical reactions usually liberate heat or absorb heat.

- How is activation energy related to chemical reactions?
- What factors affect the rate of a chemical reaction?

Key Terms

- activation energy
- concentration
- catalyst
- enzyme
- inhibitor

Lab zone Standards Warm-Up

Can You Speed Up or Slow Down a Reaction?

1. Put on your safety goggles and lab apron.
2. Obtain three 125-mL solutions of vitamin C and water—one at room temperature, one at about 75°C, and one chilled to between 5°C and 10°C.
3. Add 3 drops of iodine solution to each container and stir each with a clean spoon. Compare changes you observe in the solutions.
4. Clean up your work area and wash your hands.

Think It Over

Inferring What conclusion can you make about the effect of temperature on the reaction of iodine and vitamin C?

With a splintering crash, a bolt of lightning strikes a tree in the forest. The lightning splits the tree and sets fire to the leaves on the ground below it. The leaves are dry and crisp from drought. The crackling fire burns a black patch in the leaves. The flames leap to nearby dry twigs and branches on the ground. Soon, the forest underbrush is blazing, and the barks of trees start burning. Miles away in an observation tower, a ranger spots the fire and calls in the alarm—"Forest fire!"

Forest fires happen only under certain conditions. Many factors contribute to forest fires—lightning and drought to name just two. But, in general, wood does not always burn easily. Yet, once wood does begin to burn, it gives off a steady supply of heat and light. Why is it so hard to start and maintain some chemical reactions?

◀ Lightning can supply enough energy to ignite a forest fire.

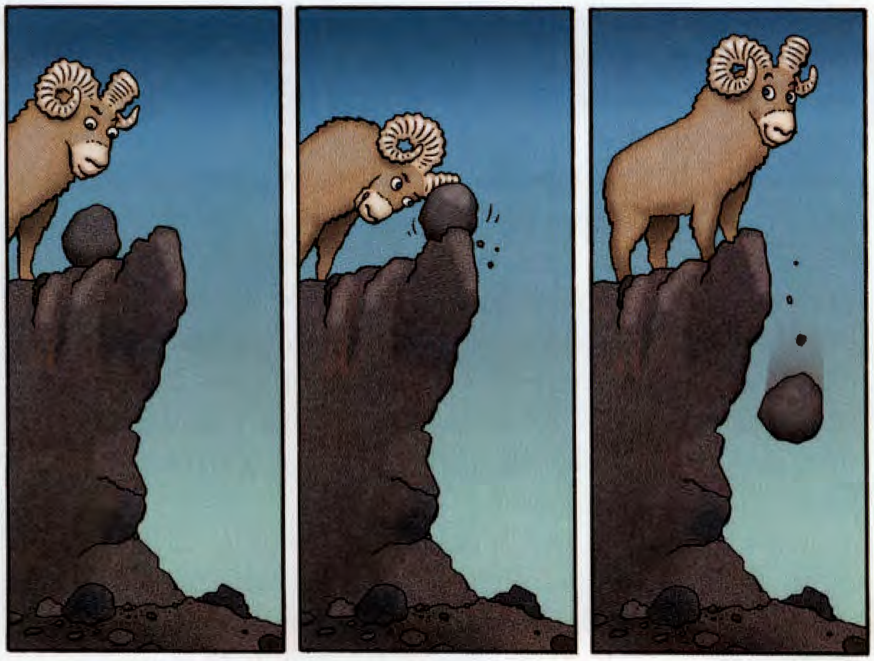


FIGURE 12
Modeling Activation Energy
The rock at the top of this hill cannot roll down the hill until a small push gets it going.
Making Models *How is this cartoon a kind of model for the role of activation energy in a chemical reaction?*

Energy and Reactions

To understand why it can be hard to start some chemical reactions, look at Figure 12. The rock at the top of the hill can fall over the cliff, releasing energy when it crashes into the rocks at the bottom. Yet it remains motionless until it's pushed over the small hump.

Activation Energy Every chemical reaction is like that rock. A reaction won't begin until the reactants have enough energy to push them "over the hump." The energy is used to break the chemical bonds of the reactants. Then, the atoms begin to form the new chemical bonds of the products. **Activation energy** is the minimum amount of energy needed to start a chemical reaction. **All chemical reactions require a certain amount of activation energy to get started.**

Consider the reaction in which hydrogen and oxygen form water. This reaction gives off a large amount of energy. But if you just mix the two gases together, they can remain unchanged for years. For the reaction to start, a tiny amount of activation energy is needed—even just an electric spark. Once a few molecules of hydrogen and oxygen react, the rest will quickly follow because the first few reactions provide activation energy for more molecules to react. Overall, the reaction releases more energy than it uses. Recall from Section 1 that this type of reaction is described as exothermic.

Reading Checkpoint **What is the function of a spark in a reaction between hydrogen gas and oxygen gas?**

Video Field Trip
Discovery Channel School
Chemical Reactions

Exothermic and Endothermic Reactions Every chemical reaction needs activation energy to get started. Whether or not a reaction needs still more energy from the environment to keep going depends on if it is exothermic or endothermic.

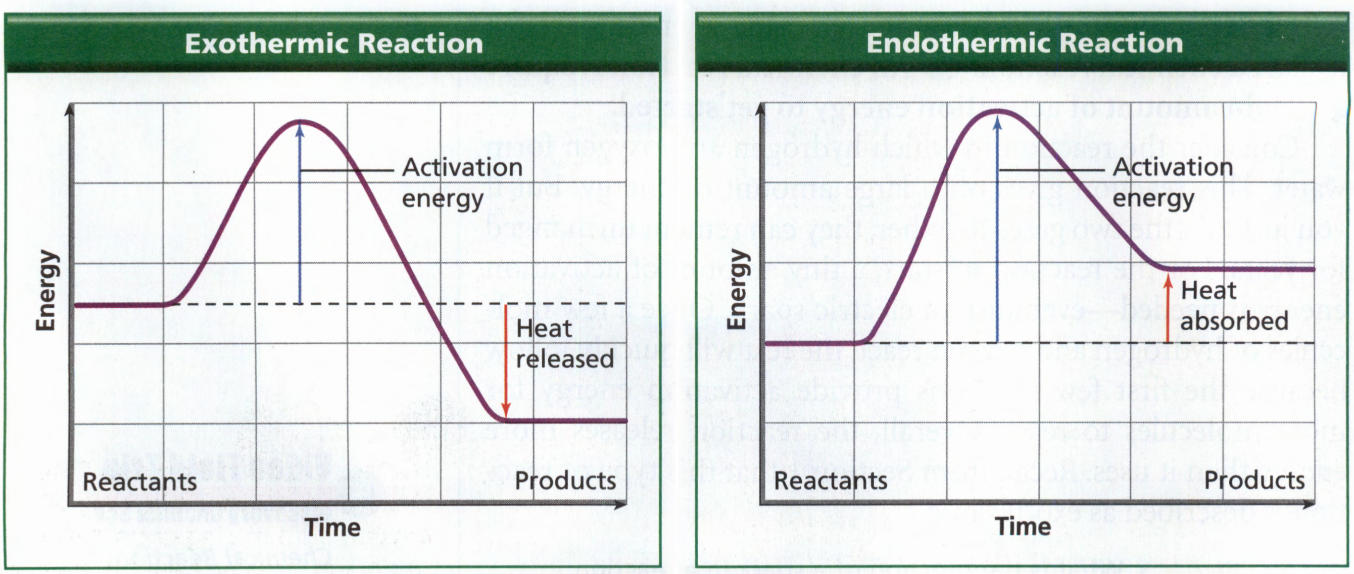
Exothermic reactions follow the pattern you can see in the first diagram in Figure 13. The dotted line marks the energy of the reactants before the reaction begins. The peak in the graph shows the activation energy. Notice that at the end of the reaction, the products have less energy than the reactants. This difference results in a release of heat. The burning of fuel, such as wood, natural gas, or oil, is an example of an exothermic reaction. People can make use of the heat that is released to warm their homes and cook food.

Now look at the graph of an endothermic reaction on the right of Figure 13. Endothermic reactions also need activation energy to get started. But, in addition, they need energy to keep going. Notice that the energy of the products is higher than that of the reactants. This difference tells you that the reaction must absorb energy to continue.

When you placed baking soda in vinegar in the Standards Warm-Up in Section 1, the thermal energy already present in the solution was enough to start the reaction. The reaction continued by drawing energy from the solution, making the solution feel colder.

Reading Checkpoint **In what type of reaction do the reactants have less energy than the products?**

FIGURE 13
Energy Changes in Chemical Reactions
Both exothermic and endothermic reactions need energy to get started. **Reading Graphs** *What does the peak in the curve in each graph represent?*



Rates of Chemical Reactions

Chemical reactions don't all occur at the same rate. Some, like explosions, are very fast. Others, like the rusting of iron, are much slower. Also, a particular reaction can occur at different rates depending on the conditions.

If you want to make a chemical reaction happen faster, you need to get more reactant particles together more often and with more energy. To slow down a reaction, you need to do the opposite. **Factors that affect rates of reaction include surface area, temperature, concentration, and the presence of catalysts or inhibitors.**

Surface Area Look at Figure 14. The wreckage used to be a grain elevator. It exploded when grain dust ignited in the air above the stored grain. Although the grain itself doesn't react violently in air, the grain dust can. This difference is related to surface area. When a chunk of solid substance reacts with a liquid or gas, only the particles on the surface of the solid come into contact with the other reactant. But if you break the solid into smaller pieces, more particles are exposed and the reaction happens faster. Sometimes, speeding up a reaction this way is dangerous. Other times, increasing surface area can be useful. For example, chewing your food breaks it into smaller pieces that your body can digest more easily and quickly.

Lab zone Skills Activity

Interpreting Data

1. Measure the length and width of a face of a gelatin cube.
2. Calculate the area of that face of the cube.
   Area = length × width
3. Repeat for each of the other five faces. Then add the six values to get the total surface area.
4. Using a plastic knife, cut the cube in half. Add the surface areas of the two pieces to get a new total.

5. How did the original total surface area compare with the total area after the cube was cut?
6. Predict the total surface area if you cut each cube in two again. If you have time, test your prediction.

FIGURE 14
Surface Area and Reaction Rate
Grain dust reacts explosively with oxygen. Minimizing grain dust in a grain elevator can help prevent an accident like the one shown here.

Temperature Another way to increase the rate of a reaction is to increase its temperature. When you heat a substance, its particles move faster. Faster-moving particles increase the reaction rate in two ways. First, the particles come in contact more often, which means there are more chances for a reaction to happen. Second, faster-moving particles have more energy. This increased energy causes more particles of the reactants to get over the activation energy "hump."

In contrast, reducing temperature slows down reaction rates. For example, milk contains bacteria, which carry out thousands of chemical reactions as they live and reproduce. At room temperature, those reactions happen faster and milk spoils more quickly. You store milk and other foods in the refrigerator because keeping foods cold slows down those reactions, so your foods stay fresh longer.

Concentration A third way to increase the rate of a chemical reaction is to increase the concentration of the reactants. **Concentration** is the amount of a substance in a given volume. For example, adding a small spoonful of sugar to a glass of lemonade will make it sweet. But adding a large spoonful of sugar makes the lemonade sweeter. The glass with more sugar has a greater concentration of sugar molecules.

Increasing the concentration of reactants supplies more particles to react. Compare the two reactions of acid and magnesium metal in Figure 15. The test tube on the left has a lower concentration of acid. This reaction is slower than the one on the right, where the acid concentration is higher. You see evidence for the increased rate of reaction in the greater amount of gas bubbles produced.

Reading Checkpoint **Why may an increase in temperature affect the rate of a chemical reaction?**

FIGURE 15
Concentration and Reaction Rate
Bubbles of hydrogen gas form when magnesium reacts with acid. The solution heats up quickly, indicating that the reaction is exothermic.
Relating Cause and Effect *What makes the reaction faster in the test tube on the right?*

Catalysts Another way to control the rate of a reaction is to change the activation energy needed. A **catalyst** (KAT uh list) is a material that increases the rate of a reaction by lowering the activation energy. Although catalysts affect a reaction's rate, they are not permanently changed by a reaction. For this reason catalysts are not considered reactants.

Many chemical reactions happen at temperatures that would kill living things. Yet, some of these reactions are necessary for life. The cells in your body (as in all living things) contain biological catalysts called **enzymes** (EN zymz). Your body has thousands of different enzymes. Each one is specific—it affects only one chemical reaction.

As shown in Figure 16, enzymes provide a surface on which reactions can take place. By bringing reactant molecules close together, the enzyme lowers the activation energy needed. In this way, enzymes make chemical reactions that are necessary for life happen at a low temperature.

Inhibitors Sometimes a reaction is more useful when it can be slowed down rather than speeded up. A material used to decrease the rate of a reaction is an **inhibitor.** Most inhibitors work by preventing reactants from coming together. Usually they combine with one of the reactants either permanently or temporarily. Inhibitors include preservatives added to food products to prevent them from becoming stale or spoiling.

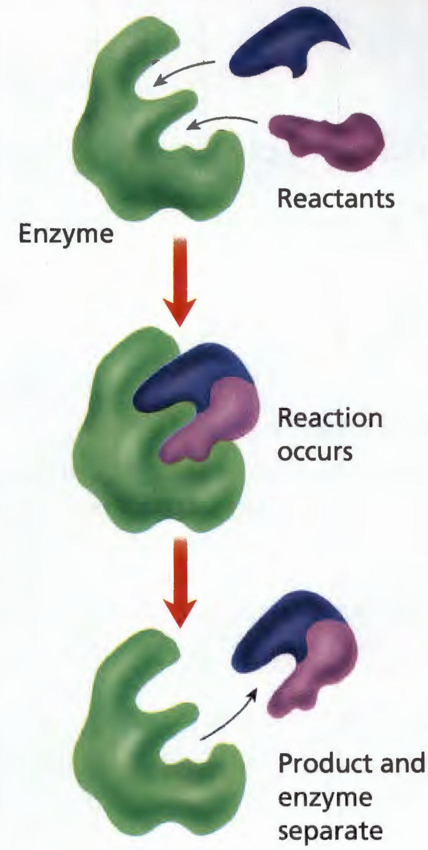


FIGURE 16
Enzyme Action
After a reaction, an enzyme molecule is unchanged.

Section 3 Assessment

S 8.5.a, 8.5.c,
E-LA: Reading 8.2.4

Target Reading Skill **Take Notes** Review your notes for this section. What are two main ideas that you noted concerning rates of chemical reactions?

Reviewing Key Concepts

1. a. **Defining** What is activation energy?
   b. **Describing** What role does activation energy play in chemical reactions?
   c. **Making Generalizations** Look at the diagram in Figure 13, and make a generalization about activation energy in exothermic and endothermic reactions.
2. a. **Identifying** What are four ways that chemists can control the rates of chemical reactions?
   b. **Applying Concepts** Which would react more quickly in a chemical reaction: a single sugar cube or an equal mass of granulated sugar crystals? Explain.

Lab zone At-Home Activity

Comparing Reaction Rates Place an iron nail in a plastic cup. Add enough water to almost cover the nail. Place a small piece of fine steel wool in another cup and add the same amount of water. Ask family members to predict what will happen overnight. The next day, examine the nail and steel wool. Compare the amount of rust on each. Were your family's predictions correct? Explain how surface areas affect reaction rates.

Lab zone **Skills Lab**

Temperature and Enzyme Activity

S 8.5.a, 8.9.a

Problem

Hydrogen peroxide is a poisonous waste product of reactions in living things. Catalase is an enzyme that speeds up the breakdown of hydrogen peroxide into water and oxygen gas. How does temperature affect the action of the enzyme catalase?

Skills Focus

calculating, graphing, interpreting data, drawing conclusions

Materials

- forceps
- stopwatch
- test tube with a one-hole stopper
- 0.1% hydrogen peroxide solution
- filter paper disks soaked in liver preparation (catalase enzyme) and kept at four different temperatures (room temperature, 0–4°C, 37°C, and 100°C)
- container to hold water (beaker or bowl)

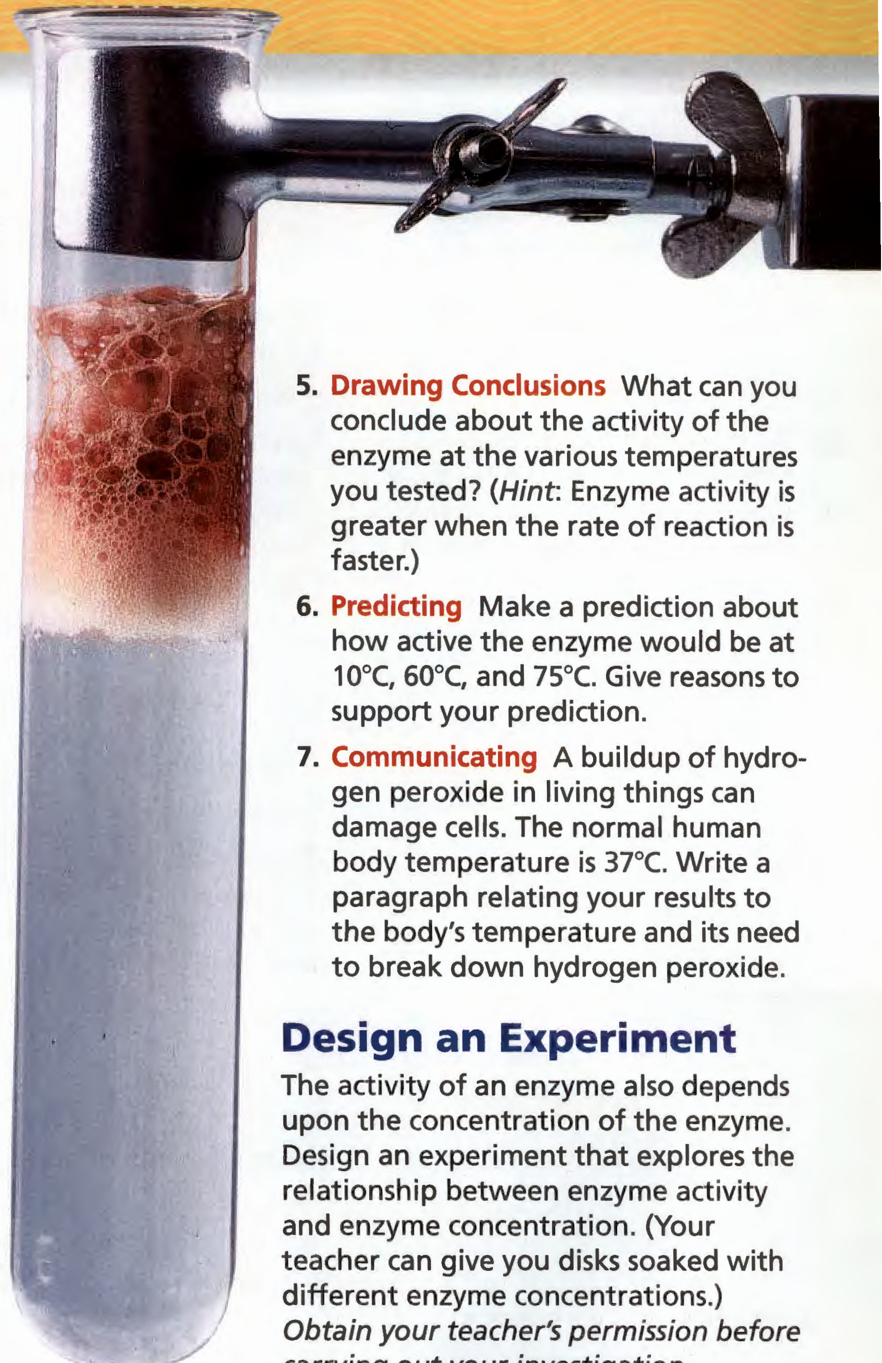
Procedure

1. Write a hypothesis explaining how the action of the catalase enzyme is related to temperature.

Data Table		
Temperature (°C)	Time (s)	Average Time for Class (s)
0		
*		
37		
100		

*Ask your teacher for the room temperature.

2. Make a data table like the one below. Get the room temperature from your teacher.
3. Fill a container with water. Then fill a test tube with 0.1% hydrogen peroxide solution until the test tube is overflowing. Do this over a sink or the container of water.
4. Moisten the small end of a one-hole stopper with water.
5. Using forceps, remove a filter paper disk soaked in liver preparation (catalase enzyme) that has been kept at room temperature. Stick it to the moistened end of the one-hole stopper. Your partner should be ready with the stopwatch for the next step.
6. Place the stopper firmly into the test tube, hold your thumb over the hole, and quickly invert the test tube. Start the stopwatch. Put the inverted end of the test tube into the container of water, as shown in the photograph, and remove your thumb.



This test tube shows the vigorous reaction that occurs between hydrogen peroxide and catalase that is found in the blood. ▶

7. If the hydrogen peroxide breaks down, oxygen will be produced. Oxygen bubbles will cling to the disk and cause it to float. Record the time it takes for the disk to rise to the top. If the disk does not rise within 30 seconds, record "no reaction" and go on to Step 8.
8. Rinse the test tube and repeat the procedure with catalase enzyme disks kept at 0°C, 37°C, and 100°C. **CAUTION:** *When you remove the disk kept in the hot water bath, do not use your bare hands. Avoid spilling the hot water.*

Analyze and Conclude

1. **Calculating** Calculate the average time for each temperature based on the results of the entire class. Enter the results in your data table.
2. **Graphing** Make a line graph of the data you collected. Label the horizontal axis (*x*-axis) "Temperature" with a scale from 0°C to 100°C. Label the vertical axis (*y*-axis) "Time" with a scale from 0 to 30 seconds. Plot the class average time for each temperature.
3. **Interpreting Data** What evidence do you have that your hypothesis from Step 1 is either supported or not supported?
4. **Interpreting Data** How is the time it takes the disk to rise to the top of the inverted tube related to the rate of the reaction?
5. **Drawing Conclusions** What can you conclude about the activity of the enzyme at the various temperatures you tested? (*Hint*: Enzyme activity is greater when the rate of reaction is faster.)
6. **Predicting** Make a prediction about how active the enzyme would be at 10°C, 60°C, and 75°C. Give reasons to support your prediction.
7. **Communicating** A buildup of hydrogen peroxide in living things can damage cells. The normal human body temperature is 37°C. Write a paragraph relating your results to the body's temperature and its need to break down hydrogen peroxide.

Design an Experiment

The activity of an enzyme also depends upon the concentration of the enzyme. Design an experiment that explores the relationship between enzyme activity and enzyme concentration. (Your teacher can give you disks soaked with different enzyme concentrations.) *Obtain your teacher's permission before carrying out your investigation.*

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Section 4

Fire and Fire Safety

CALIFORNIA Standards Focus

S 8.5.c Students know chemical reactions usually liberate heat or absorb heat.

- What are the three things necessary to maintain a fire?
- Why should you know about the causes of fire and how to prevent a fire?

Key Terms

- combustion
- fuel

Lab zone **Standards Warm-Up**

How Does Baking Soda Affect a Fire?

1. Put on your safety goggles.
2. Secure a small candle in a holder or a ball of clay. After instructions from your teacher, use a match to light the candle.
3. Place a beaker next to the candle. Measure 1 large spoonful of baking soda into the beaker. Add about 100 mL of water and stir. Add about 100 mL of vinegar.
4. As soon as the mixture stops foaming, tip the beaker as if you are pouring something out of it onto the flame. **CAUTION:** *Do not pour any liquid on the candle.*
5. Observe what happens to the flame.

Think It Over

Developing Hypotheses The gas produced in the beaker was carbon dioxide, CO_2. Based on the results of this experiment, develop a hypothesis to explain what you observed in Step 5.

The call comes in. Fire! A blaze has been spotted in a warehouse near gasoline storage tanks. Firefighters scramble aboard the ladder truck and the hose truck. Lights flash, sirens blare, and traffic swerves to clear a path for the trucks. The firefighters know from their training that fire is a chemical reaction that can be controlled—but only if they reach it in time.

Firefighters battle a blaze. ▼

Understanding Fire

Fire is the result of **combustion**, a rapid reaction between oxygen and a fuel. A **fuel** is a material that releases energy when it burns. Common fuels include oil, wood, gasoline, natural gas, and paper. Combustion of these types of fuel always produces carbon dioxide and water. When fuels don't burn completely, products such as smoke and poisonous gases may be produced.

The Fire Triangle Although a combustion reaction is very exothermic and fast, a fire cannot start unless conditions are right. **Three things necessary to start and maintain a fire are fuel, oxygen, and heat.**

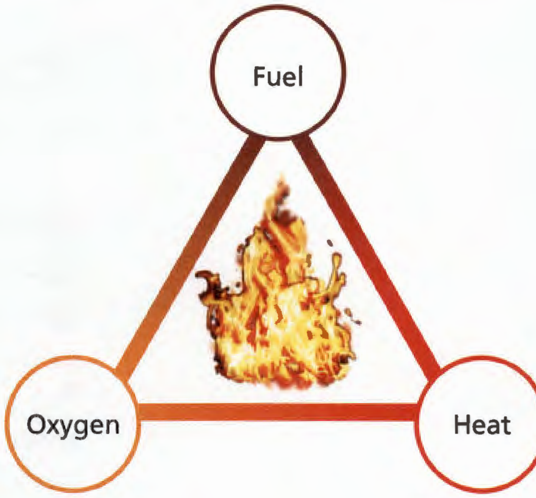
You probably know that oxygen is one of the gases in air. About 20 percent of the air around you is composed of oxygen gas. If air can reach the fuel, so can oxygen. A large fire can create a strong draft that pulls air toward it. As the air around the flame is heated, it rises rapidly. Cooler air flows toward the fire, replacing the heated air and bringing a fresh supply of oxygen. If you stand in front of a fire in a fireplace, you can feel the air flow toward the fire.

Heat is a part of the "fire triangle." Fuel and oxygen can be together, but they won't react until something provides the activation energy to start combustion. This energy can come from a lighted match, an electric spark, or the heat from a stove. Once combustion starts, the heat released supplies more activation energy to keep the reaction going.

Once started, a fire can continue burning as long as all components of the fire triangle are available. Coal in abandoned mines under the town of Centralia, Pennsylvania, started burning in 1962. The coal is still burning. Many old airshafts lead into the tunnels. Because some airshafts cannot be located and sealed, air continues to flow into the mines, supporting the fire. Heat and poisonous gases coming up from the fire through cracks in the ground made living in Centralia difficult. Everyone eventually moved away. No one knows how long this fire will continue to burn.

Reading Checkpoint **What is heat's role in starting a fire?**

FIGURE 17
The Fire Triangle
The fire triangle can be controlled in the grill below. If any point of the fire triangle is missing, a fire will not continue.
Applying Concepts *How would closing the lower air vents affect the fire?*



Go Online SCI LINKS NSTA

For: Links on fire safety
Visit: www.SciLinks.org
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Controlling Fire Use your knowledge of chemical reactions to think of ways to control a fire. What if you remove one part of the fire triangle? For example, you can get the fuel away from the flames. You can also keep oxygen from getting to the fuel. Finally, you can cool the combustion reaction.

How do firefighters usually fight fires? They use hoses to spray huge amounts of water on the flames. Water removes two parts of the fire triangle. First, water covers the fuel, which keeps it from coming into contact with oxygen. Second, evaporation of the water uses a large amount of heat, causing the fire to cool. Without heat, there isn't enough energy to continue the combustion. Therefore, the reaction stops.

Home Fire Safety

Every year, fire claims thousands of lives in the United States. **If you know how to prevent fires in your home and what to do if a fire starts, you are better prepared to take action.** You may save your home or even your life! The most common sources of home fires are small heaters, cooking, and faulty electrical wiring. The fires that cause the most deaths start from carelessness with cigarettes.

Fighting Fires You can fight a small fire by using what you know about the fire triangle. For example, carbon dioxide gas can smother a fire by preventing contact between the fuel and oxygen in the air. Therefore, you can put out a small fire on the stove by throwing baking soda on it. Baking soda decomposes when heated and releases carbon dioxide gas. Or, you can use the cover of a saucepan to cut off the flow of oxygen.

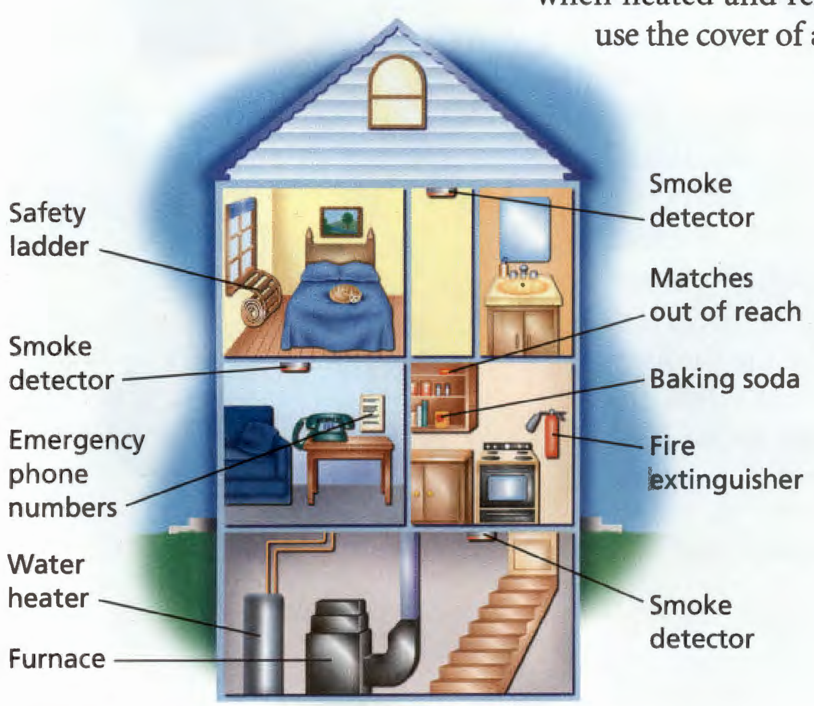

FIGURE 18
A Fire-Safe House
This fire-safe house has many fire-prevention and fire safety features. **Inferring** *Why are smoke detectors located on every floor?*

A small fire is easy to control. You can cool a match enough to stop combustion just by blowing on it. A small fire in a trash can may be doused with a pan of water. If the fire spreads to the curtains, however, even a garden hose might not deliver enough water to put it out.

One of the most effective ways to fight a small fire is with a fire extinguisher. But a fire that is growing as you fight it is out of control. If a fire is out of control, there is only one safe thing to do—get away from the fire and call the fire department.

Preventing Trouble The best form of fire safety is prevention. Figure 18 shows some features of a fire-safe house. You can also check your home to be sure that all flammable items are stored safely away from sources of flames, such as the kitchen stove. Fires can be dangerous and deadly, but many fires can be prevented if you are careful. Understanding the chemistry of fire gives you a way to reduce risk and increase your family's safety.

Reading Checkpoint How does baking soda put a fire out?

FIGURE 19
Fire-Prevention Devices
Fire extinguishers and baking soda can be used to interrupt the fire triangle. Smoke detectors can help you identify a fire and escape to safety.

Section 4 Assessment

S 8.5.c, E-LA: Reading 8.2.4

Target Reading Skill **Take Notes** Review your notes for this section. What important details did you include about preventing fires in your home?

Reviewing Key Concepts

1. a. **Listing** What three things are required for combustion?
   b. **Explaining** How does the fire triangle help you control fire?
   c. **Applying Concepts** To stop a forest fire, firefighters may remove all the trees in a strip of land that lies in the path of the fire. What part of the fire triangle is affected? Explain.
2. a. **Reviewing** Why is it important to know about the causes of fire and how to prevent fires?
   b. **Identifying** What are the three most common causes of home fires?
   c. **Problem Solving** Choose one common cause of home fires. Describe measures that can be taken to prevent fires of this type.

Lab zone At-Home Activity

Family Safety Plan Work with your family to formulate a fire safety plan. How can fires be prevented in your home? How can fires be put out if they occur? Is there a functioning smoke detector on each floor of the home, especially near the bedrooms? How can the fire department be contacted in an emergency? Design a fire escape route. Make sure all family members know the route as well as a meeting place outside.

Chapter 6 Study Guide

The BIG Idea Chemical reactions are processes in which atoms are rearranged into different combinations of molecules.

1 Observing Chemical Change

Key Concepts S 8.5.a, 8.5.c

- Changes in matter can be described in terms of physical changes and chemical changes.
- Chemical changes occur when bonds break and new bonds form.
- Chemical reactions involve changes in properties and changes in energy that you can observe.

Key Terms

matter
chemistry
physical property
chemical property
physical change
chemical change
reactant
product
precipitate
endothermic reaction
exothermic reaction

2 Describing Chemical Reactions

Key Concepts S 8.5.b

- Chemical equations use chemical formulas and other symbols instead of words to summarize a reaction.
- In chemical reactions, the number of atoms stays the same no matter how they are arranged, so their total mass stays the same.
- To describe a reaction accurately, a chemical equation must show the same number of each type of atom on both sides of the equation.
- Three general types of chemical reactions are synthesis, decomposition, and replacement.

Key Terms

chemical equation
conservation of matter
open system
closed system
coefficient
synthesis
decomposition
replacement

3 Controlling Chemical Reactions

Key Concepts S 8.5.a, 8.5.c

- All chemical reactions require a certain amount of activation energy to get started.
- Factors that affect rates of reaction include surface area, temperature, concentration, and the presence of catalysts or inhibitors.

Key Terms

activation energy
concentration
catalyst
enzyme
inhibitor

4 Fire and Fire Safety

Key Concepts S 8.5.c

- The following three things are necessary to start and maintain a fire—fuel, oxygen, and heat.
- If you know how to prevent fires in your home and what to do if a fire starts, you are better prepared to take action.

Key Terms

combustion
fuel

Review and Assessment

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Target Reading Skill

Take Notes In your notebook, create a two-column note-taking organizer for Section 2: Describing Chemical Reactions. Include summary statements.

Recall Clues and Questions	Notes
What are chemical equations?	Chemical equation: an easy way to show a chemical reaction. • Chemical formulas—symbols for elements in a compound • Structure of an equation—

Reviewing Key Terms

Choose the letter of the best answer.

1. Which of the following is *not* a physical property?
   a. flexibility
   b. ability to catch fire
   c. melting point
   d. ability to conduct electricity
2. A chemical reaction that gives off heat is likely to be
   a. endothermic. **b.** a precipitate.
   c. a physical change. **d.** exothermic.
3. You can balance a chemical equation by changing the
   a. subscripts. **b.** coefficients.
   c. reactants. **d.** products.
4. A chemical reaction in which two elements combine to form a compound is called a
   a. synthesis. **b.** replacement.
   c. decomposition. **d.** precipitation.
5. The activation energy of a chemical reaction
   a. is supplied by a catalyst.
   b. is released at the end.
   c. starts the reaction.
   d. changes with time.
6. A chemical reaction in which a fuel combines rapidly with oxygen is a(n)
   a. inhibited reaction.
   b. combustion reaction.
   c. enzyme reaction.
   d. endothermic reaction.

Complete the following sentences so that your answers clearly explain the key terms.

7. A burning candle is an example of a **chemical change,** or a change in which ________ .
8. The left side of a chemical equation lists the **reactants,** or the substances that ________ .
9. By measuring the masses of the reactants and products of a reaction, you can demonstrate the principle of **conservation of matter,** which states that ________ .
10. One factor that can affect reaction rates is a reactant's **concentration,** which refers to ________ .

Writing in Science

Explanation You are a writer for a children's book about chemistry. Write a paragraph that young children would understand that explains the concept of "activation energy." Be sure to use examples, such as the burning of wood or gas.

Video Assessment
Discovery Channel School
Chemical Reactions

Review and Assessment

Checking Concepts

11. What are the two kinds of changes that occur in matter? Describe how you can tell one from the other.

12. Why can't you balance a chemical equation by changing the subscripts of the reactants or the products?

13. You find the mass of a piece of iron metal, let it rust, and measure the mass again. The mass has increased. Does this violate the principle of conservation of matter? Explain.

14. How do enzymes in your body make chemical reactions occur at safe temperatures?

15. Why does spraying water on a fire help to put the fire out?

16. How are inhibitors useful in controlling chemical reactions?

Thinking Critically

17. Problem Solving Steel that is exposed to water and salt rusts quickly. If you were a shipbuilder, how would you protect a new ship? Explain why your solution works.

18. Classifying The following are balanced equations for chemical reactions. Classify each of the equations as synthesis, decomposition, or replacement.

a. $2\ Al + Fe_2O_3 \longrightarrow 2\ Fe + Al_2O_3$

b. $2\ Ag + S \longrightarrow Ag_2S$

c. $CaCO_3 \longrightarrow CaO + CO_2$

d. $2\ NO + O_2 \longrightarrow 2\ NO_2$

19. Relating Cause and Effect Firefighters open doors very carefully because sometimes a room will burst violently into flames when the door is opened. Based on your knowledge of the fire triangle, explain why this happens.

20. Inferring Some statues are made of materials that can react in acid rain and begin to dissolve. It has been observed that statues with smooth surfaces are dissolved by acid rain much slower than statues with very detailed carvings. Explain this observation.

Math Practice

Balance the chemical equations in Questions 21–24.

21. $MgO + HBr \longrightarrow MgBr_2 + H_2O$

22. $N_2 + O_2 \longrightarrow N_2O_5$

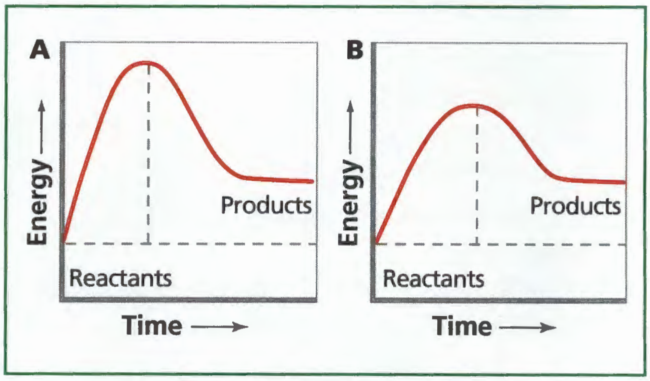
23. $C_2H_4 + O_2 \longrightarrow CO_2 + H_2O$

24. $Fe + HCl \longrightarrow FeCl_2 + H_2$

Applying Skills

Use the energy diagram to answer Questions 25–27.

The two graphs below represent the same chemical reaction under different conditions.



25. Interpreting Data How does the energy of the products compare with the energy of the reactants?

26. Classifying Tell whether this reaction is exothermic or endothermic.

27. Applying Concepts What change in condition might account for the lower "hump" in the second graph? Explain.

Lab zone Standards Investigation

Performance Assessment Make a poster of your test results. Display your reaction chamber for the class. Discuss how your chamber was built to the specifications agreed upon by the class. Describe its safety features. Based on your results, rate how effectively your chamber works as a closed system.

CALIFORNIA Standards Practice

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Choose the letter of the best answer.

1. Which of the following is the *best* evidence for a chemical reaction?
- **A** gas bubbles
- **B** formation of a new substance
- **C** change of state
- **D** change in temperature

S 8.5.a

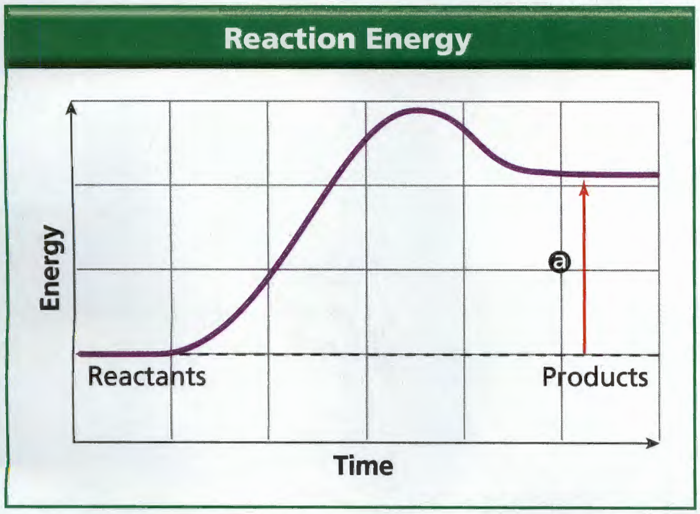
2. Which statement best describes what happens to chemical bonds in a reaction?
- **A** Bonds are only broken, not formed
- **B** Bonds are only formed, not broken.
- **C** Bonds in the reactants are broken, and bonds in the products are formed.
- **D** Bonds are neither formed nor broken.

S 8.5.c

3. Which shows a balanced chemical equation for the decomposition of aluminum oxide (Al_2O_3)?
- **A** $Al_2O_3 \longrightarrow 2\,Al + O_2$
- **B** $Al_2O_3 \longrightarrow 2\,Al + 3\,O_2$
- **C** $2\,Al_2O_3 \longrightarrow 4\,Al + O_2$
- **D** $2\,Al_2O_3 \longrightarrow 4\,Al + 3\,O_2$

S 8.5.b

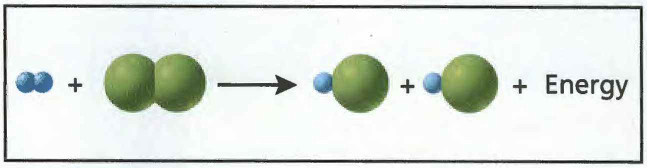
Use the diagram below to answer Question 4.



4. The quantity (a) in the diagram represents the
- **A** activation energy of the reaction.
- **B** energy absorbed by the reaction.
- **C** energy released by the reaction.
- **D** temperature of the reactants.

S 8.5.c

Base your answers to Questions 5 and 6 on the diagram below. The diagram represents molecules of two different elements that are gases. The elements react chemically to produce a third gas.



5. The diagram represents a(n)
- **A** endothermic reaction in which energy is released.
- **B** exothermic reaction in which energy is absorbed.
- **C** exothermic reaction in which energy is released.
- **D** reaction in which energy is destroyed.

S 8.5.c

6. What can be inferred from the diagram?
- **A** Matter is not created or destroyed in a chemical reaction.
- **B** The rate of a reaction depends on the surface area of the reactants.
- **C** A gas molecule always consists of two identical atoms.
- **D** The product is carbon monoxide gas.

S 8.5.b

Apply the BIG Idea

7. The major component of natural gas is methane (CH_4). When methane burns in oxygen gas (O_2), carbon dioxide (CO_2) and water vapor (H_2O) are produced. Write a balanced equation for this reaction. Explain why the burning of methane is a chemical change, not a physical change. Does this change absorb heat or liberate heat? **S 8.5**