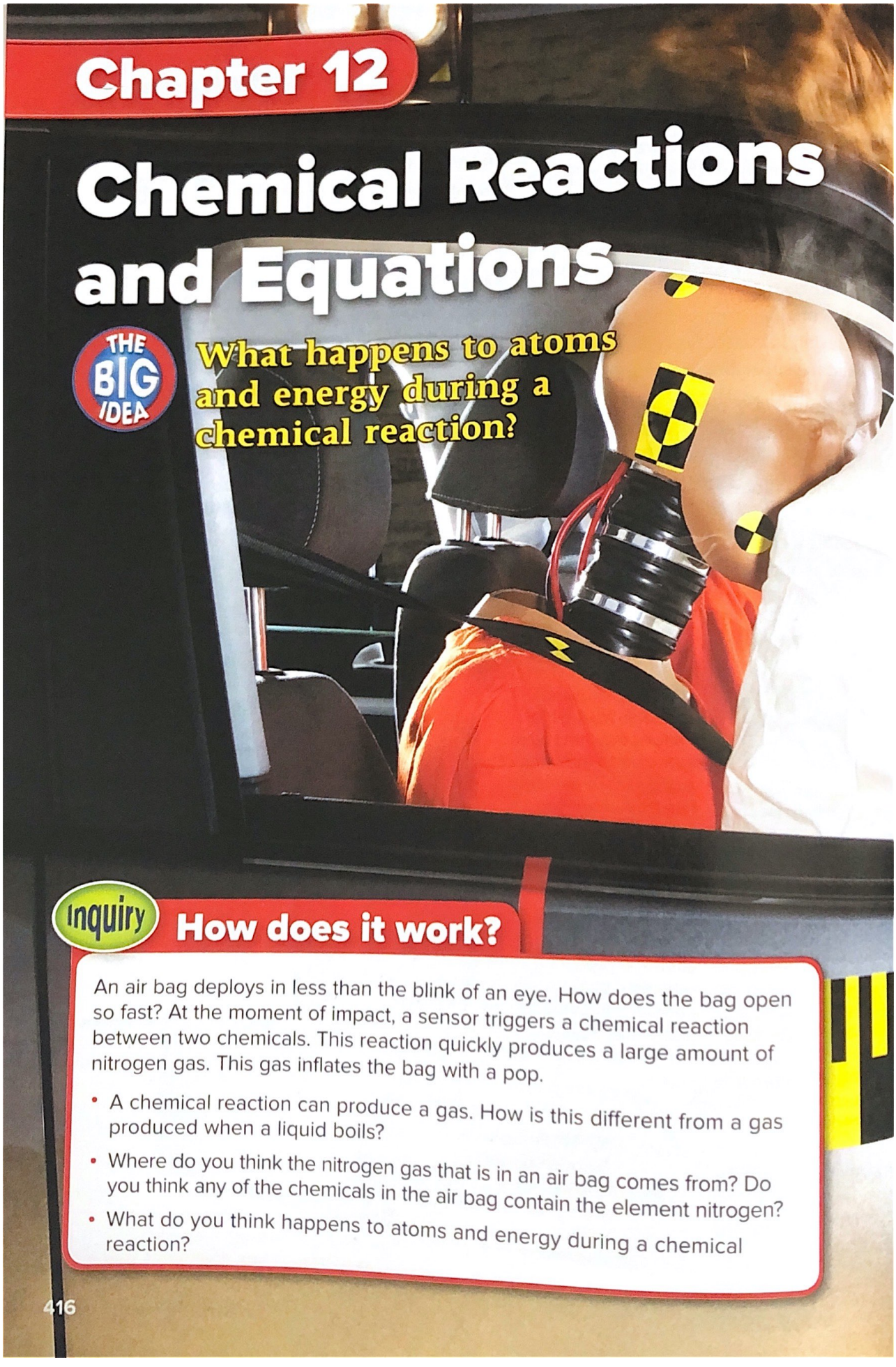
Chapter 12

Chemical Reactions and Equations



THE BIG IDEA

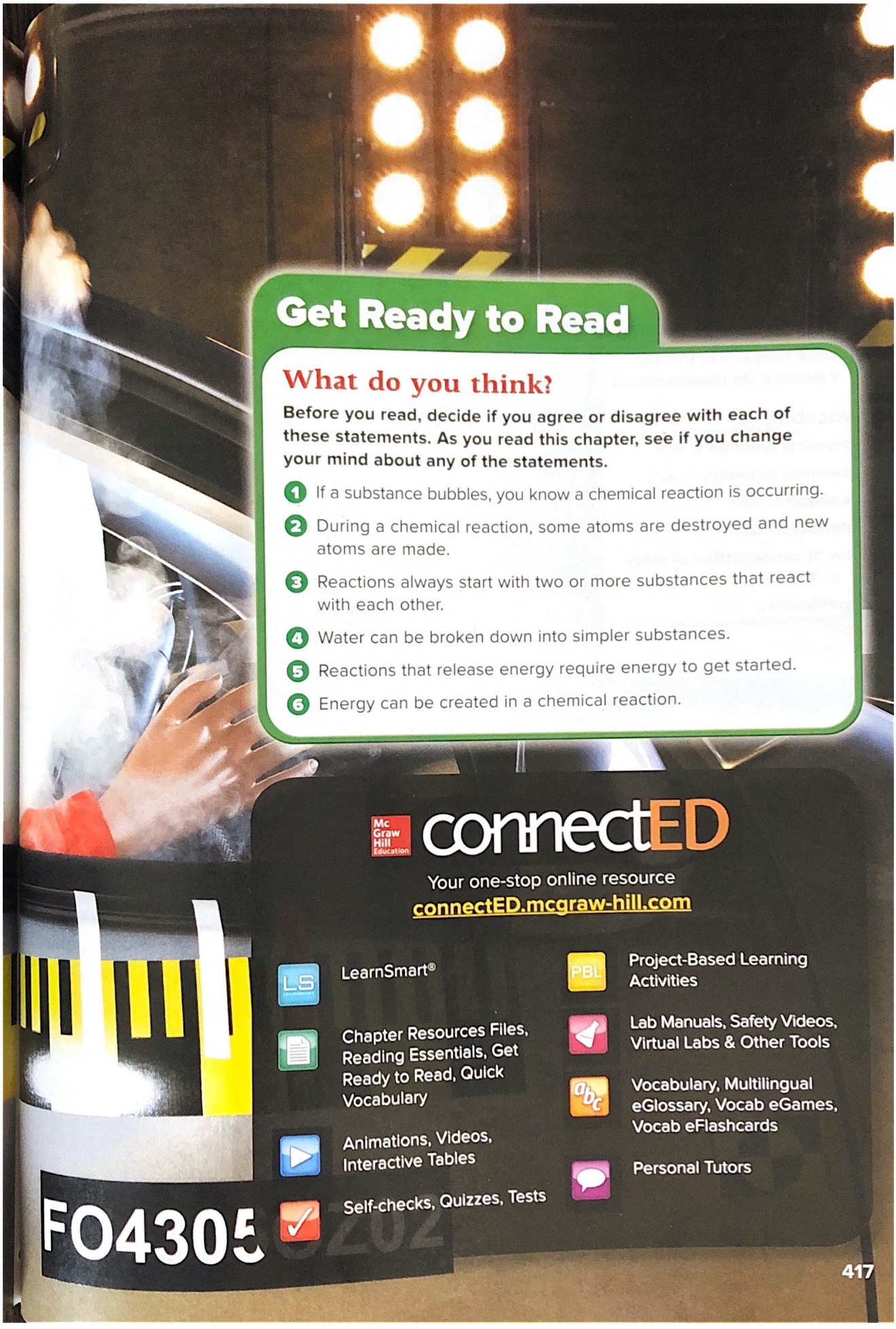
What happens to atoms and energy during a chemical reaction?

Inquiry

How does it work?

An air bag deploys in less than the blink of an eye. How does the bag open so fast? At the moment of impact, a sensor triggers a chemical reaction between two chemicals. This reaction quickly produces a large amount of nitrogen gas. This gas inflates the bag with a pop.

- A chemical reaction can produce a gas. How is this different from a gas produced when a liquid boils?
- Where do you think the nitrogen gas that is in an air bag comes from? Do you think any of the chemicals in the air bag contain the element nitrogen?
- What do you think happens to atoms and energy during a chemical reaction?



Get Ready to Read

What do you think?

Before you read, decide if you agree or disagree with each of these statements. As you read this chapter, see if you change your mind about any of the statements.

1. If a substance bubbles, you know a chemical reaction is occurring.
2. During a chemical reaction, some atoms are destroyed and new atoms are made.
3. Reactions always start with two or more substances that react with each other.
4. Water can be broken down into simpler substances.
5. Reactions that release energy require energy to get started.
6. Energy can be created in a chemical reaction.

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Lesson 1

Understanding Chemical Reactions

Reading Guide

Key Concepts

ESSENTIAL QUESTIONS

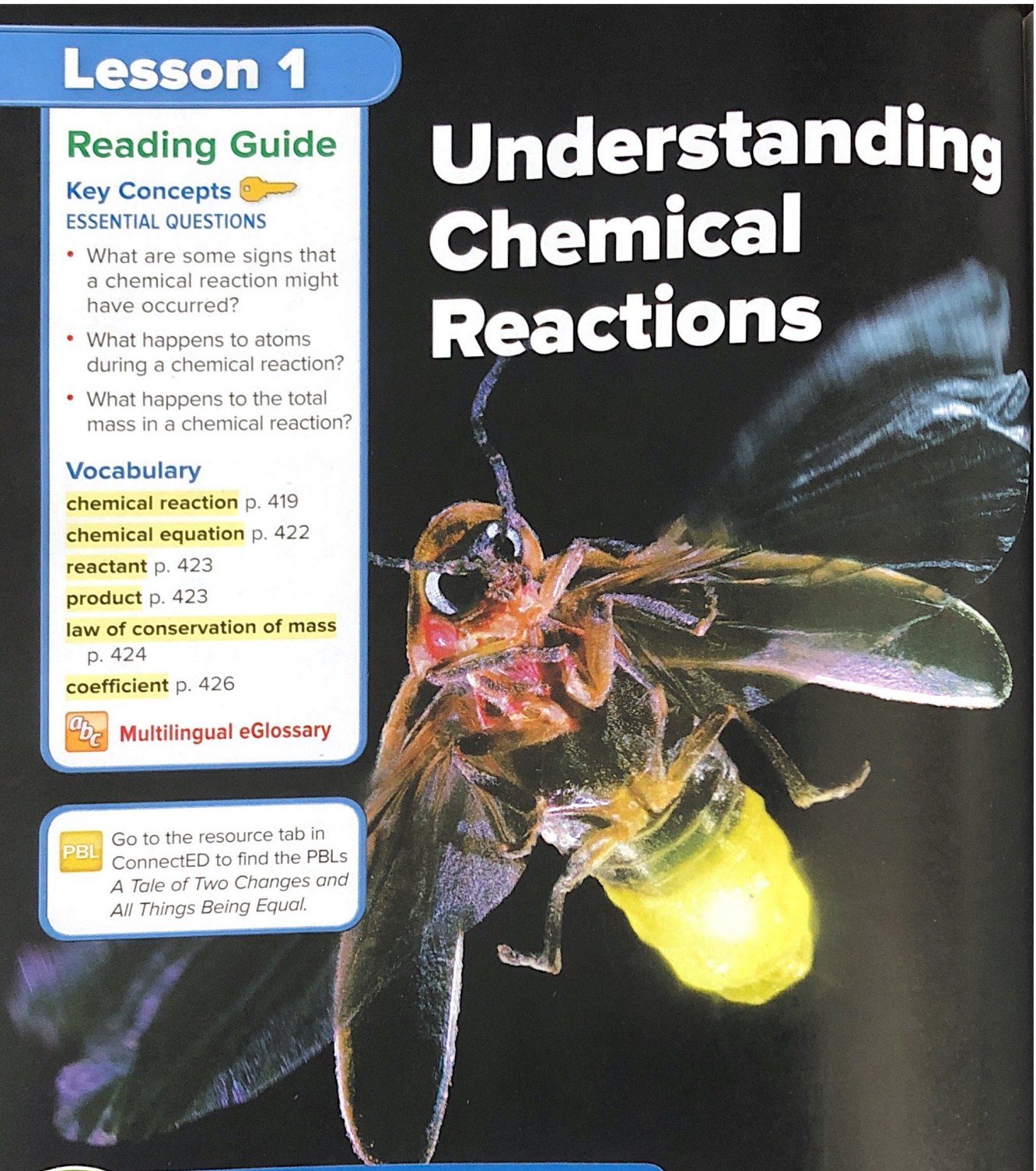
- What are some signs that a chemical reaction might have occurred?
- What happens to atoms during a chemical reaction?
- What happens to the total mass in a chemical reaction?

Vocabulary

chemical reaction p. 419
chemical equation p. 422
reactant p. 423
product p. 423
law of conservation of mass p. 424
coefficient p. 426

Multilingual eGlossary

PBL Go to the resource tab in ConnectED to find the PBLs *A Tale of Two Changes* and *All Things Being Equal.*



Darwin Dale/Photo Researchers, Inc.

Inquiry Does it run on batteries?

Flashes of light from fireflies dot summer evening skies in many parts of the United States. But, firefly light doesn't come from batteries. Fireflies make light using a process called bioluminescence (bi oh lew muh NE cents). In this process, chemicals in the firefly's body combine in a two-step process and make new chemicals and light.

Launch Lab

15–20 minutes

Where did it come from?

Does a boiled egg have more mass than a raw egg? What happens when liquids change to a solid?

1. Read and complete a lab safety form.
2. Use a **graduated cylinder** to add 25 mL of **solution A** to a **self-sealing plastic bag.** Place a **stoppered test tube** containing **solution B** into the bag. Be careful not to dislodge the stopper.
3. Seal the bag completely, and wipe off any moisture on the outside with a **paper towel.** Place the bag on the **balance.** Record the total mass in your Science Journal.
4. Without opening the bag, remove the stopper from the test tube and allow the liquids to mix. Observe and record what happens.
5. Place the sealed bag and its contents back on the balance. Read and record the mass.

Think About This

1. What did you observe when the liquids mixed? How would you account for this observation?
2. Did the mass of the bag's contents change? If so, could the change have been due to the precision of the balance, or did the matter in the bag change its mass? Explain.
3. **Key Concept** Do you think matter was gained or lost in the bag? How can you tell?

Changes in Matter

When you put liquid water in a freezer, it changes to solid water, or ice. When you pour brownie batter into a pan and bake it, the liquid batter changes to a solid, too. In both cases, a liquid changes to a solid. Are these changes the same?

Physical Changes

Recall that matter can undergo two types of changes–chemical or physical. A physical change does not produce new substances. The substances that exist before and after the change are the same, although they might have different physical properties. This is what happens when liquid water freezes. Its physical properties change from a liquid to a solid, but the water, H_2O, does not change into a different substance. Water molecules are always made up of two hydrogen atoms bonded to one oxygen atom regardless of whether they are solid, liquid, or gas.

Chemical Changes

Recall that during a chemical change, one or more substances change into new substances. The starting substances and the substances produced have different physical and chemical properties. For example, when brownie batter bakes, a chemical change occurs. Many of the substances in the baked brownies are different from the substances in the batter. As a result, baked brownies have physical and chemical properties that are different from those of brownie batter.

A chemical change also is called a chemical reaction. These terms mean the same thing. *A* **chemical reaction** *is a process in which atoms of one or more substances rearrange to form one or more new substances.* In this lesson, you will read what happens to atoms during a reaction and how these changes can be described using equations.

Reading Check What types of properties change during a chemical reaction?

Hutchings Photography/Digital Light Source

Signs of a Chemical Reaction

How can you tell if a chemical reaction has taken place? You have read that the substances before and after a reaction have different properties. You might think that you could look for changes in properties as a sign that a reaction occurred. In fact, changes in the physical properties of color, state of matter, and odor are all signs that a chemical reaction might have occurred. Another sign of a chemical reaction is a change in energy. If substances get warmer or cooler or if they give off light or sound, it is likely that a reaction has occurred. Some signs that a chemical reaction might have occurred are shown in **Figure 1**.

However, these signs are not proof of a chemical change. For example, bubbles appear when water boils. But, bubbles also appear when baking soda and vinegar react and form carbon dioxide gas. How can you be sure that a chemical reaction has taken place? The only way to know is to study the chemical properties of the substances before and after the change. If they have different chemical properties, then the substances have undergone a chemical reaction.

Key Concept Check What are some signs that a chemical reaction might have occurred?

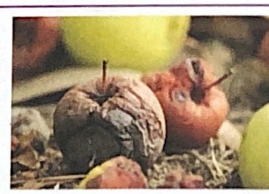
Figure 1 You can detect a chemical reaction by looking for changes in properties and changes in energy of the substances that reacted.

Change in Properties

Change in color
Bright copper changes to green when the copper reacts with certain gases in the air.

Formation of bubbles
Bubbles of carbon dioxide form when baking soda is added to vinegar.

Change in odor
When food burns or rots, a change in odor is a sign of chemical change.

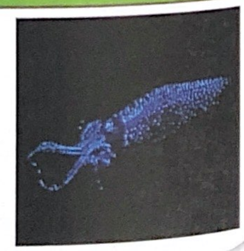


Formation of a precipitate
A precipitate is a solid formed when two liquids react.

Change in Energy

Warming or cooling
Thermal energy is either given off or absorbed during a chemical change.

Release of light
A firefly squid gives off light as the result of a chemical change.



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What happens in a chemical reaction?

During a chemical reaction, one or more substances react and form one or more new substances. How are these new substances formed?

Atoms Rearrange and Form New Substances

To understand what happens in a reaction, first review substances. Recall that there are two types of substances–elements and compounds. Substances have a fixed arrangement of atoms. For example, in a single drop of water, there are trillions of oxygen and hydrogen atoms. However, all of these atoms are arranged in the same way–two atoms of hydrogen are bonded to one atom of oxygen. If this arrangement changes, the substance is no longer water. Instead, a different substance forms with different physical and chemical properties. This is what happens during a chemical reaction. Atoms of elements or compounds rearrange and form different elements or compounds.

Bonds Break and Bonds Form

How does the rearrangement of atoms happen? Atoms rearrange when **chemical bonds** between atoms break. Recall that constantly moving particles make up all substances, including solids. As particles move, they collide with one another. If the particles collide with enough energy, the bonds between atoms can break. The atoms separate, rearrange, and new bonds can form. The reaction that forms hydrogen and oxygen from water is shown in **Figure 2.** Adding electric energy to water molecules can cause this reaction. The added energy causes bonds between the hydrogen atoms and the oxygen atoms to break. After the bonds between the atoms in water molecules break, new bonds can form between pairs of hydrogen atoms and between pairs of oxygen atoms.

Key Concept Check What happens to atoms during a chemical reaction?

REVIEW VOCABULARY

chemical bond
an attraction between atoms when electrons are shared, transferred, or pooled

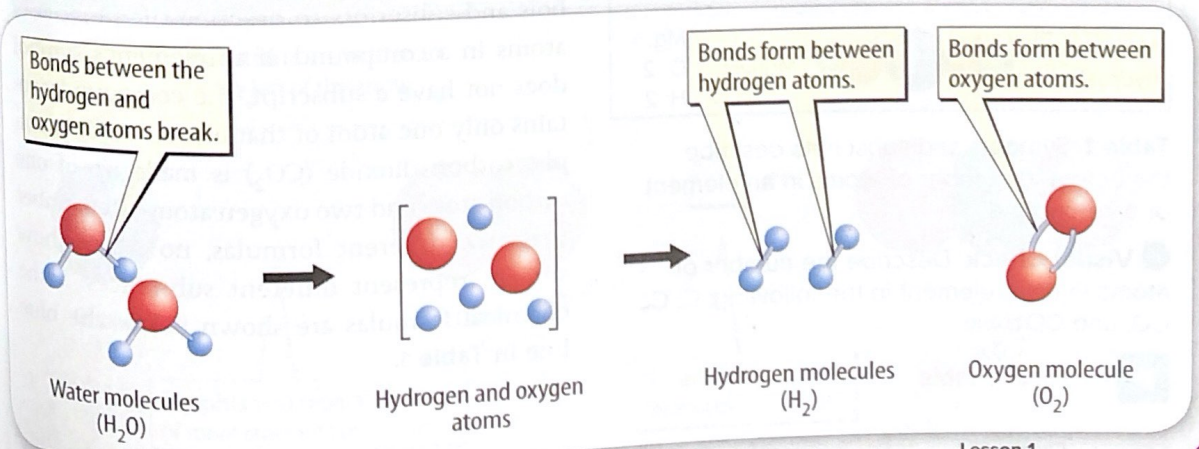


Figure 2 Notice that no new atoms are created in a chemical reaction. The existing atoms rearrange and form new substances.

Table 1 Symbols and Formulas of Some Elements and Compounds

Substance	Formula	# of atoms
Carbon	C	C: 1
Copper	Cu	Cu: 1
Cobalt	Co	Co: 1
Oxygen	O_2	O: 2
Hydrogen	H_2	H: 2
Chlorine	Cl_2	Cl: 2
Carbon dioxide	CO_2	C: 1 O: 2
Carbon monoxide	CO	C: 1 O: 1
Water	H_2O	H: 2 O: 1
Hydrogen peroxide	H_2O_2	H: 2 O: 2
Glucose	$C_6H_{12}O_6$	C: 6 H: 12 O: 6
Sodium chloride	NaCl	Na: 1 Cl: 1
Magnesium hydroxide	$Mg(OH)_2$	Mg: 1 O: 2 H: 2

Table 1 Symbols and subscripts describe the type and number of atoms in an element or a compound.

Visual Check Describe the number of atoms in each element in the following: C, Co, CO, and CO_2.

Interactive Table

Chemical Equations

Suppose your teacher asks you to produce a specific reaction in your science laboratory. How might your teacher describe the reaction to you? He or she might say something such as "react baking soda and vinegar to form sodium acetate, water, and carbon dioxide." It is more likely that your teacher will describe the reaction in the form of a chemical equation. *A* **chemical equation** *is a description of a reaction using element symbols and chemical formulas.* Element symbols represent elements. Chemical formulas represent compounds.

Element Symbols

Recall that symbols of elements are shown in the periodic table. For example, the symbol for carbon is C. The symbol for copper is Cu. Each element can exist as just one atom. However, some elements exist in nature as diatomic molecules–two atoms of the same element bonded together. A formula for one of these diatomic elements includes the element's symbol and the subscript *2*. A subscript describes the number of atoms of an element in a compound. Oxygen (O_2) and hydrogen (H_2) are examples of diatomic molecules. Some element symbols are shown above the blue line in **Table 1.**

Chemical Formulas

When atoms of two or more different elements bond, they form a compound. Recall that a chemical formula uses elements' symbols and subscripts to describe the number of atoms in a compound. If an element's symbol does not have a subscript, the compound contains only one atom of that element. For example, carbon dioxide (CO_2) is made up of one carbon atom and two oxygen atoms. Remember that two different formulas, no matter how similar, represent different substances. Some chemical formulas are shown below the blue line in **Table 1.**

Writing Chemical Equations

A chemical equation includes both the substances that react and the substances that are formed in a chemical reaction. *The starting substances in a chemical reaction are* **reactants.** *The substances produced by the chemical reaction are* **products.** **Figure 3** shows how a chemical equation is written. Chemical formulas are used to describe the reactants and the products. The reactants are written to the left of an arrow, and the products are written to the right of the arrow. Two or more reactants or products are separated by a plus sign. The general structure for an equation is:

reactant + reactant → product + product

When writing chemical equations, it is important to use correct chemical formulas for the reactants and the products. For example, suppose a certain chemical reaction produces carbon dioxide and water. The product carbon dioxide would be written as CO_2 and not as CO. CO is the formula for carbon monoxide, which is not the same compound as CO_2. Water would be written as H_2O and not as H_2O_2, the formula for hydrogen peroxide.

Figure 3 An equation is read much like a sentence. This equation is read as "carbon plus oxygen produces carbon dioxide."

MiniLab 10 minutes

How does an equation represent a reaction?

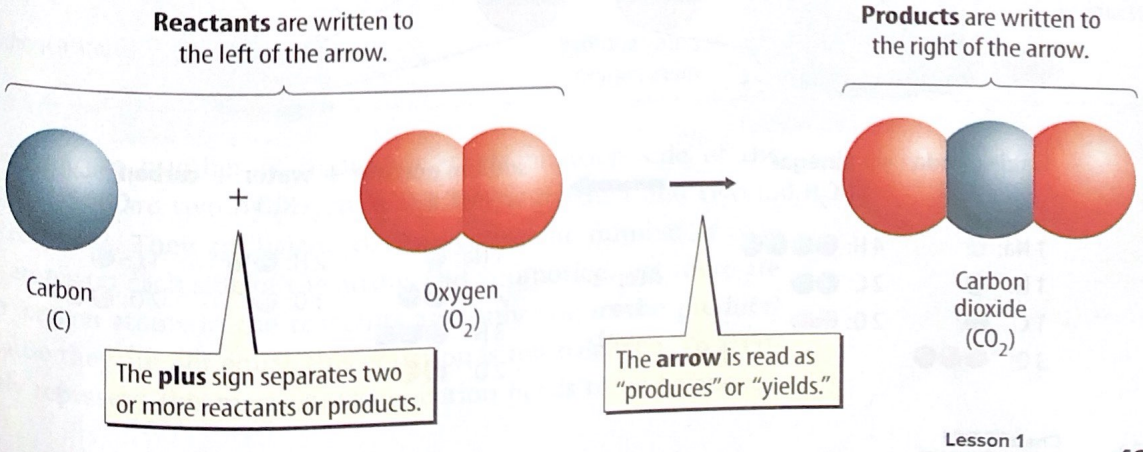
Sulfur dioxide (SO_2) and oxygen (O_2) react and form sulfur trioxide (SO_3). How does an equation represent the reaction?

1. Read and complete a lab safety form.
2. Use **yellow modeling clay** to model two atoms of sulfur. Use **red modeling clay** to model six atoms of oxygen.
3. Make two molecules of SO_2 with a sulfur atom in the middle of each molecule. Make one molecule of O_2. Sketch the models in your Science Journal.
4. Rearrange atoms to form two molecules of SO_3. Place a sulfur atom in the middle of each molecule. Sketch the models in your Science Journal.

Analyze and Conclude

1. **Identify** the reactants and the products in this chemical reaction.
2. **Write** a chemical equation for this reaction.
3. **Explain** What do the letters represent in the equation? The numbers?
4. **Key Concept** In terms of chemical bonds, what did you model by pulling molecules apart and building new ones?

Parts of an Equation



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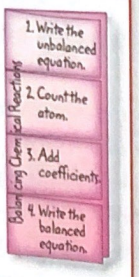
WORD ORIGIN

product
from Latin *producere*, means "bring forth"

FOLDABLES®

Make a vertical four-tab book. Label it as shown. Use it to study the steps of balancing equations.



Conservation of Mass

A French chemist named Antoine Lavoisier (AN twan • luh VWAH see ay) (1743–1794) discovered something interesting about chemical reactions. In a series of experiments, Lavoisier measured the masses of substances before and after a chemical reaction inside a closed container. He found that the total mass of the reactants always equaled the total mass of the **products.** Lavoisier's results led to the law of conservation of mass. *The* **law of conservation of mass** *states that the total mass of the reactants before a chemical reaction is the same as the total mass of the products after the chemical reaction.*

Atoms are conserved.

The discovery of atoms provided an explanation for Lavoisier's observations. Mass is conserved in a reaction because atoms are conserved. Recall that during a chemical reaction, bonds break and new bonds form. However, atoms are not destroyed, and no new atoms form. All atoms at the start of a chemical reaction are present at the end of the reaction. **Figure 4** shows that mass is conserved in the reaction between baking soda and vinegar.

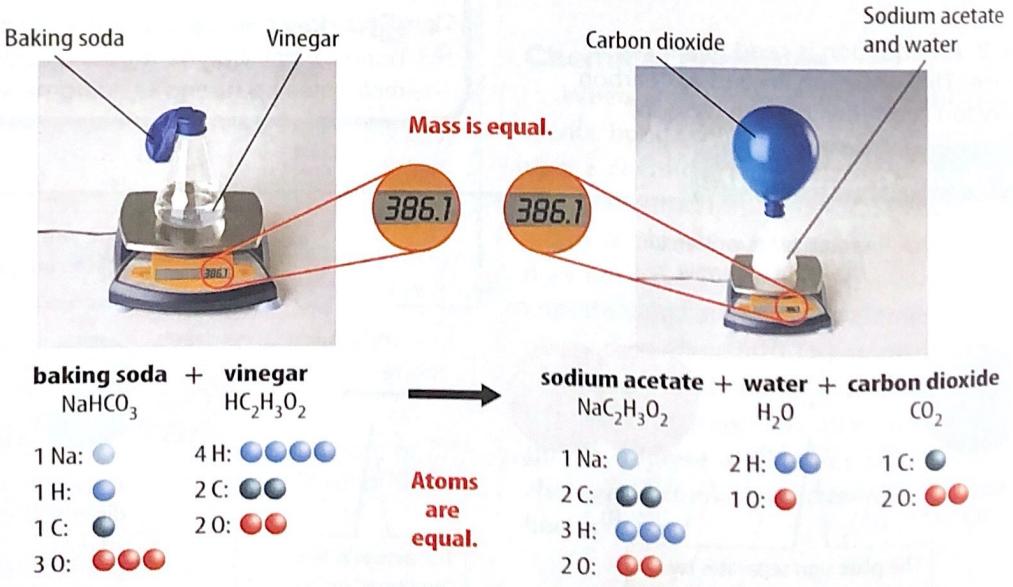
Key Concept Check What happens to the total mass of the reactants in a chemical reaction?

Figure 4 As this reaction takes place, the mass on the balance remains the same, showing that mass is conserved.

Conservation of Mass

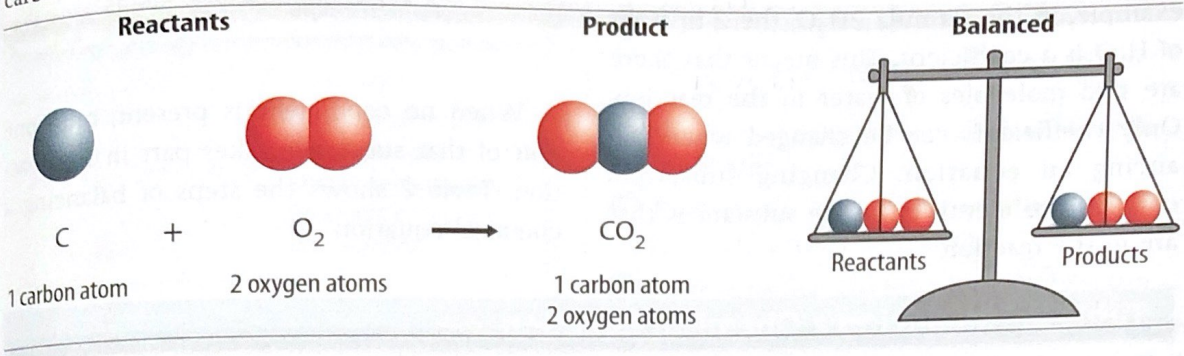
The baking soda is contained in a balloon. The balloon is attached to a flask that contains vinegar.

When the balloon is tipped up, the baking soda pours into the vinegar. The reaction forms a gas that is collected in the balloon.



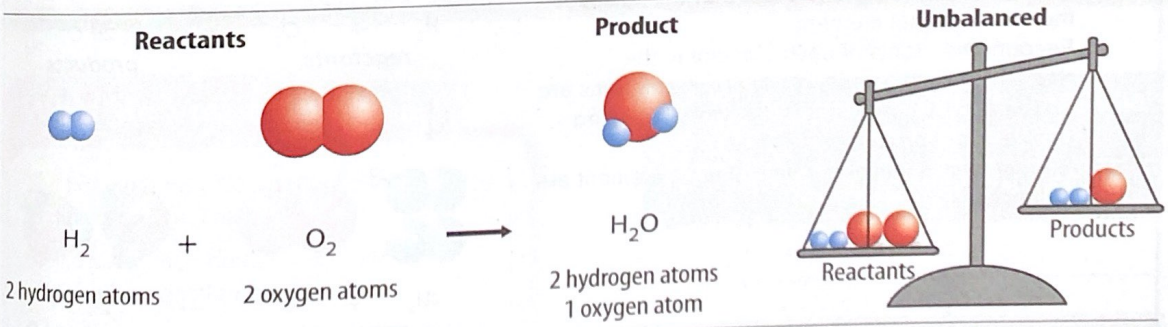
Is an equation balanced?

How does a chemical equation show that atoms are conserved? An equation is written so that the number of atoms of each element is the same, or balanced, on each side of the arrow. The equation showing the reaction between carbon and oxygen that produces carbon dioxide is shown below. Remember that oxygen is written as O_2 because it is a diatomic molecule. The formula for carbon dioxide is CO_2.



Is there the same number of carbon atoms on each side of the arrow? Yes, there is one carbon atom on the left and one on the right. Carbon is balanced. Is oxygen balanced? There are two oxygen atoms on each side of the arrow. Oxygen also is balanced. The atoms of all elements are balanced. Therefore, the equation is balanced.

You might think a balanced equation happens automatically when you write the symbols and formulas for reactants and products. However, this usually is not the case. For example, the reaction between hydrogen (H_2) and oxygen (O_2) that forms water (H_2O) is shown below.



Count the number of hydrogen atoms on each side of the arrow. There are two hydrogen atoms in the product and two in the reactants. They are balanced. Now count the number of oxygen atoms on each side of the arrow. Did you notice that there are two oxygen atoms in the reactants and only one in the product? Because they are not equal, this equation is not balanced. To accurately represent this reaction, the equation needs to be balanced.

Balancing Chemical Equations

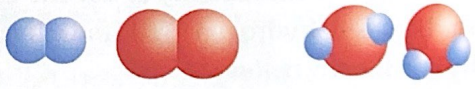
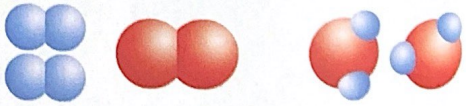
When you balance a chemical equation, you count the atoms in the reactants and the products and then add coefficients to balance the number of atoms. *A* **coefficient** *is a number placed in front of an element symbol or chemical formula in an equation.* It is the number of units of that substance in the reaction. For example, in the formula $2H_2O$, the *2* in front of H_2O is a coefficient, This means that there are two molecules of water in the reaction. Only coefficients can be changed when balancing an equation. Changing subscripts changes the identities of the substances that are in the reaction.

If one molecule of water contains two hydrogen atoms and one oxygen atom, how many H and O atoms are in two molecules of water ($2H_2O$)? Multiply each by 2.

2×2 H atoms $= 4$ H atoms
2×1 O atom $= 2$ O atoms

When no coefficient is present, only one unit of that substance takes part in the reaction. **Table 2** shows the steps of balancing a chemical equation.

Table 2 Balancing a Chemical Equation

1 **Write the unbalanced equation.** Make sure that all chemical formulas are correct.	H_2 + O_2 → H_2O *reactants* *products*
2 **Count atoms of each element in the reactants and in the products.** **a.** Note which, if any, elements have a balanced number of atoms on each side of the equation. Which atoms are not balanced? **b.** If all of the atoms are balanced, the equation is balanced.	 H_2 + O_2 → H_2O *reactants* *products* *H* = 2 *H* = 2 *O* = 2 *O* = 1
3 **Add coefficients to balance the atoms.** **a.** Pick an element in the equation that is not balanced, such as oxygen. Write a coefficient in front of a reactant or a product that will balance the atoms of that element. **b.** Recount the atoms of each element in the reactants and the products. Note which atoms are not balanced. Some atoms that were balanced before might no longer be balanced. **c.** Repeat step 3 until the atoms of each element are balanced.	 H_2 + O_2 → $2H_2O$ *reactants* *products* *H* = 2 *H* = 4 *O* = 2 *O* = 2  $2H_2$ + O_2 → $2H_2O$ *reactants* *products* *H* = 4 *H* = 4 *O* = 2 *O* = 2
4 **Write the balanced chemical equation** including the coefficients.	$2H_2$ + O_2 = $2H_2O$

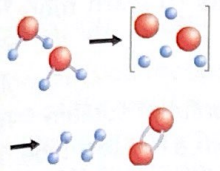
Visual Check In row 2 above, which element is not balanced? In the top of row 3, which element is not balanced?

Personal Tutor

Lesson 1 Review

Online Quiz

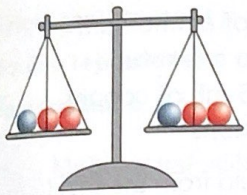
Visual Summary



A chemical reaction is a process in which bonds break and atoms rearrange, forming new bonds.

$2H_2 + O_2 \rightarrow 2H_2O$

A chemical equation uses symbols to show reactants and products of a chemical reaction.



The mass and the number of each type of atom do not change during a chemical reaction. This is the law of conservation of mass.

FOLDABLES

Use your lesson Foldable to review the lesson. Save your Foldable for the project at the end of the chapter.

What do you think NOW?

You first read the statements below at the beginning of the chapter.

1. If a substance bubbles, you know a chemical reaction is occurring.
2. During a chemical reaction, some atoms are destroyed and new atoms are made.

Did you change your mind about whether you agree or disagree with the statements? Rewrite any false statements to make them true.

Use Vocabulary

1. **Define** *reactants* and *products*.

Understand Key Concepts

2. Which is a sign of a chemical reaction?
   - **A.** chemical properties change
   - **B.** physical properties change
   - **C.** a gas forms
   - **D.** a solid forms

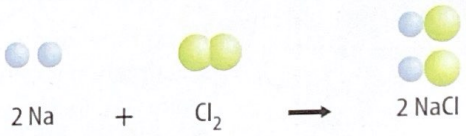
3. **Explain** why subscripts cannot change when balancing a chemical equation.

4. **Infer** Is the reaction below possible? Explain why or why not.

$$H_2O + NaOH \rightarrow NaCl + H_2$$

Interpret Graphics

5. **Describe** the reaction below by listing the bonds that break and the bonds that form.



6. **Interpret** Copy and complete the table to determine if this equation is balanced:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Is this reaction balanced? Explain.

Type of Atom	Number of Atoms in the Balanced Chemical Equation	
	Reactants	Products

Critical Thinking

7. Balance this chemical equation. Hint: Balance Al last and then use a multiple of 2 and 3.

$$Al + HCl \rightarrow AlCl_3 + H_2$$

What can you learn from an experiment?

Materials

test tubes and rack

ammonium hydroxide (NH_4OH)

aluminum foil

sodium bicarbonate ($NaHCO_3$)

Also needed: copper foil, tongs, salt water, copper sulfate solution ($CuSO_4$), 25-mL graduated cylinder, Bunsen burner, plastic spoon, toothpick, ring stand and clamp, splints, matches, paper towel

Safety

Observing reactions allows you to compare different types of changes that can occur. You can then design new experiments to learn more about reactions.

Learn It

If you have never tested for a chemical reaction before, it is helpful to **follow a procedure.** A procedure tells you which materials to use and what steps to take.

Try It

1. Read and complete a safety form.
2. Copy the table into your Science Journal. During each procedure, record observations in the table.
3a. Dip a strip of aluminum foil into salt water in a test tube for about 1 min to remove the coating.
3b. Place 5 mL of copper sulfate solution in a test tube. Lift the aluminum foil from the salt water. Drop it into the test tube of copper sulfate so that the bottom part is in the liquid. Look for evidence of a chemical change. Set the test tube in a rack, and do the other procedures.
4. Use tongs to hold a small piece of copper foil in a flame for 3 min. Set the foil on a heat-proof surface, and allow it to cool. Use a toothpick to examine the product.
5. Place a spoonful of sodium bicarbonate in a dry test tube. Clamp the tube to a ring stand at a 45° angle. Point the mouth of the tube away from people. Move a burner flame back and forth under the tube. Observe the reaction. Test for carbon dioxide with a lighted wood splint.
6. Add 1 drop of ammonium hydroxide to a test tube containing 5 mL of copper sulfate solution.
7. Pour the liquid from the test tube in step 3b into a clean test tube. Dump the aluminum onto a paper towel. Record your observations of both the liquid and the solid.

Apply It

8. Using the table, write a balanced equation for each reaction.
9. Why did the color of the copper sulfate disappear in step 3b?
10. **Key Concept** What changes in properties and changes in energy indicate that the changes are chemical as well as physical?

Step	Reactants	Products	Observations and Evidence of Chemical Reaction
3+7	$Al + CuSO_4$	$Cu + Al_2(SO_4)_3$	
4	$Cu + O_2$	CuO	
5	$NaHCO_3$	$CO_2 + Na_2CO_3 + H_2O$	
6	$NH_4OH + CuSO_4$	$(NH_4)_2SO_4 + Cu(OH)_2$	

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