chapter 19

Chemical Reactions

section 1 Chemical Changes

What You'll Learn

- how to identify the reactants and products in a chemical reaction
- how a chemical reaction follows the law of conservation of mass
- how chemists describe chemical changes with equations

Before You Read

Think about what happens when you bake a cake. On the lines below, describe how the ingredients change form throughout the process of baking a cake.

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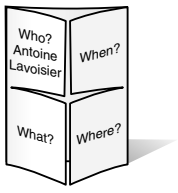
_____

Study Coach

Create a Quiz As you read this section, write the headings that ask questions. Write questions you have about the main ideas and the vocabulary terms. After you read, make your questions into a quiz.

FOLDABLES™

A Ask Questions Make a Foldable like the one shown. As you read the section, answer the questions about Antoine Lavoisier and his experiments.



Read to Learn

Describing Chemical Reactions

Dark, mysterious mixtures react. Gases bubble up and expand out of liquids. Powerful aromas move through the air. Are you in a chemistry lab? No. You are in your kitchen baking a chocolate cake. Many chemical reactions occur in the kitchen.

Chemical reactions take place everywhere. They even happen inside your body. A **chemical reaction** is a change in which one or more substances are converted into new substances. A **reactant** is one of the substances that react. A **product** is one of the new substances that are produced. You can describe a chemical reaction as follows:

$$\text{reactants} \xrightarrow{\text{produce}} \text{products}$$

Conservation of Mass

By the 1770s, chemistry was changing from an art to a science. Scientists began to study chemical reactions more carefully. The French chemist Antoine Lavoisier discovered an important rule. He found that the total mass of the products of a chemical reaction always equals the mass of the reactants. This is called the conservation of mass.

The figures above show an experiment he performed. The mass of the candle and the air in the jar (the reactants) before burning is the same as the mass of the gases and the candle (the products) after burning.

What were Lavoisier's experiments?

Lavoisier wanted to know exactly what happened when substances changed form. To answer this question, he experimented with mercury. He put solid mercury(II) oxide, a red powder, in a sealed container. He found the mass of the reactant in the container. When he heated the container, the mercury(II) oxide changed to a silvery liquid. It also gave off a gas. The silvery liquid was the metal mercury. He then found the mass of the products in the container again. It was the same as the mass before the experiment.

mercury(II) oxide		oxygen	plus	mercury
10g	=	0.3g	+	9.7g

Lavoisier also figured out that the gas produced in the experiment, oxygen, was a part of air. He did this by heating mercury metal with air. He saw that a portion of the air combined with mercury to make mercury(II) oxide. He studied the effect of oxygen on living animals and humans.

Lavoisier did hundreds of experiments in his laboratory. He confirmed that in a chemical reaction, matter is not created or destroyed, but is conserved. This principle is known as the law of conservation of mass. This means that the total starting mass of the reactants of a chemical reaction always equals the total final mass of the products.

Why is Lavoisier called the father of modern chemistry?

Lavoisier's explanation of the law of conservation of mass started modern science. He also was the first to describe a chemical reaction called combustion. These discoveries are why Lavoisier is called the father of modern chemistry.

Picture This

1. **Compare** How does the height of the right side of the scale in the first figure compare to the height of the right side of the scale in the second figure?

Reading Check

2. **Identify** What did Lavoisier find about the mass of the container with reactants and the mass of the container with products in his experiment with mercury(II) oxide?

Think it Over

3. **Draw Conclusions** Imagine that chemists did not use the same rules to name compounds. How might this cause problems for a chemist who was trying to repeat an experiment done by the first chemist?

Why are names important?

Scientists needed better ways to describe their ideas. Lavoisier wanted to improve the way elements and compounds were named. He knew that if all chemists used the same names for elements and compounds, they could understand one another better. In 1787, Lavoisier and several other scientists wrote the first instructions for naming compounds. Since then, the guidelines have continued to evolve. In 1919, an organization was formed to coordinate guidelines for naming compounds. It is called the International Union of Pure and Applied Chemistry (IUPAC).

Writing Equations

It is important to include all the information when you describe a chemical reaction. What were the reactants? What did you do with them? What happened when they reacted? What were the products? When you answer all these questions, the description of the reaction can be quite long.

Scientists have a shortcut for describing chemical reactions. A **chemical equation** is a way to describe a chemical reaction using chemical formulas and other symbols. Some of the symbols used in chemical equations are shown in the table.

Symbols Used in Chemical Equations

Symbol	Meaning	Symbol	Meaning
→	produces or forms	*(aq)*	Aqueous; a substance is dissolved in water.
+	plus	heat →	The reactants are heated.
(s)	solid	light →	The reactants are exposed to light.
(l)	liquid	elec. →	An electric current is applied to the reactants.
(g)	gas		

Picture This

4. **Summarize** What does the symbol (*g*) placed next to a compound in a chemical equation mean?

Applying Math

5. **Explain** What do you notice about the numbers on the left side of the arrow and the numbers on the right side of the arrow in the chemical equation?

Look at this description of a chemical reaction:

> Nickel(II) chloride, dissolved in water, plus sodium hydroxide, dissolved in water, produces solid nickel(II) hydroxide plus sodium chloride, dissolved in water.

If you use a chemical equation, the same description is shorter and easier to understand as:

$$NiCl_2(aq) + 2NaOH(aq) \rightarrow Ni(OH)_2(s) + 2NaCl(aq)$$

Coefficients

Look again at the chemical equation on the previous page. What do the numbers to the left of NaOH and NaCl mean? Do you remember the law of conservation of mass? Matter is not made or lost in a chemical reaction. Atoms are rearranged, but they are never created or destroyed. The numbers in the equation are called coefficients. A **coefficient** shows the number of units of a substance taking part in a reaction.

Suppose you were going to make sandwiches for a picnic. You know that each sandwich needs two slices of bread, one slice of turkey, one slice of cheese, two slices of tomato, and one leaf of lettuce. If you also know how many sandwiches you need to make, you can figure out how much bread, turkey, cheese, tomato, and lettuce you need to buy so you do not have any food left over.

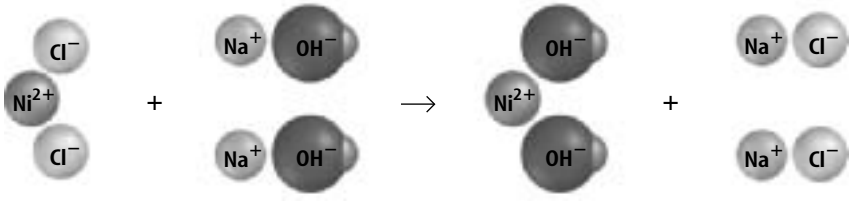
Making sandwiches is like a chemical reaction. The ingredients for the sandwiches are the reactants. The finished sandwiches are the products. The number of units of bread, turkey, cheese, tomato, and lettuce are the coefficients of the reactants. The number of finished sandwiches is the coefficient of the product. However, the quantity of each ingredient is the same in the reactants and product.

How do chemists use coefficients?

When chemists know the number of units of each reactant, they are able to add the correct amounts of reactants needed for a reaction. The units or coefficients will tell how much product will form. For example, here is the chemical equation from the example on the previous page.

$$NiCl_2(aq) + 2NaOH(aq) \rightarrow Ni(OH)_2(s) + 2NaCl(aq)$$

You can see that one unit of $NiCl_2$ and two units of NaOH produce one unit of $Ni(OH)_2$ and two units of NaCl. The figure below shows you how the coefficients affect the number of molecules in the reaction.



Reading Check

6. Explain What does a coefficient show?

Applying Math

7. Apply Suppose $NiCl_2$ reacts with NaOH. For each molecule of $NiCl_2$, how many molecules of NaOH are needed?

Picture This

8. Observe What does the 2NaOH represent?

Balancing Equations

The equation below is for Lavoisier's mercury(II) oxide reaction.

$$HgO(s) \xrightarrow{\text{heat}} Hg(l) + O_2(g)$$

How many atoms of mercury (Hg) are on each side of the equation? There is one mercury (Hg) atom on the reactant side and one mercury (Hg) atom on the product side. How many atoms of oxygen (O) are on each side? Notice that there is one oxygen (O) atom on the reactant side, but the product side has two oxygen (O) atoms.

Atoms	HgO	→	Hg	+	O_2
Hg	1		1		
O	1				2

Remember that according to the law of conservation of mass, one oxygen atom cannot become two oxygen atoms. You cannot rewrite HgO as HgO_2. That would make the number of oxygen atoms balance, but HgO and HgO_2 are not the same compound. The formula in a chemical equation must accurately represent the compounds that react.

What does a balanced equation show?

A chemical equation must be balanced. Balancing only changes the way a reaction is represented. It does not change what happens in the reaction. To balance a chemical equation, you change the coefficients. A **balanced chemical equation** has the same number of atoms of each element on each side of the equation.

How do you choose coefficients?

You often can find the coefficients to balance an equation just by guessing and checking your guess. In the mercury(II) oxide equation, the number of mercury atoms is balanced. You need to balance the number of oxygen atoms. Try putting a coefficient of 2 in front of HgO on the left side of the equation. This balances the oxygen, but not the mercury.

Atoms	2HgO	→	Hg	+	O_2
Hg	2		1		
O	2				2

Think it Over

9. Analyze Results Why does putting a coefficient of 2 in front of HgO on the left side of the equation balance the oxygen but not the mercury?

To balance the mercury, put a 2 in front of the mercury on the right side of the equation.

Atoms	2HgO	→	2Hg	+	O_2
Hg	2		2		
O	2				2

Now the equation is balanced.

$$2HgO \rightarrow 2Hg + O_2$$

What are the steps for balancing an equation?

Magnesium burns with a very bright light. Have you ever seen a flare burning at the scene of a traffic accident? The flare probably was made of magnesium. When magnesium burns, it leaves a white powder, magnesium oxide. To write a balanced chemical equation for the burning of magnesium, follow these steps.

Step 1 Write a chemical equation using formulas and symbols. Remember that oxygen is a diatomic molecule, which means that it consists of two oxygen atoms in a covalent bond.

$$Mg(s) + O_2(g) \rightarrow MgO(s)$$

Step 2 Count the atoms in the reactants and products.

Atoms	Mg	+	O_2	→	MgO
Mg	1				1
O			2		1

The magnesium atoms are balanced, but the oxygen atoms are not. So, the equation is not balanced.

Step 3 Choose coefficients to balance the equation. Remember that you cannot change the subscripts of a formula to balance the equation. Instead, try putting the coefficient 2 in front of MgO.

$$Mg(s) + O_2(g) \rightarrow 2MgO(s)$$

Think it Over

10. Apply Hydrogen (H), like oxygen, is a diatomic molecule. Write the chemical formula for hydrogen.

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Applying Math

11. Apply When lithium metal is treated with water, hydrogen gas and lithium hydroxide are produced. Balance the following chemical equation that shows this reaction.

$Li(s) + H_2O(g) \rightarrow LiOH(aq) + H_2(g)$

_____

_____

Step 4 Check the number of atoms on each side of the equation again. Now, there are two magnesium atoms on the right side of the equation and only one on the left. You need to put the coefficient 2 in front of Mg to balance the equation.

$$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$$

The above chemical equation for the burning of magnesium is balanced.

Now try one on your own. Balance the equation for the following reaction:

$$Fe(s) + Cl_2(g) \rightarrow FeCl_3(s)$$

Write the correct number of atoms in the column under the each element. Then write the balanced numbers in the bottom row.

Atoms	Fe	Cl_2	→	Fe	Cl_3
Fe			→		
Cl			→		
balanced					

What are moles? To help chemists figure out how much of a substance is needed to get a certain reaction, they use a counting unit called the mole (mol). One **mole** is the amount of a substance that contains 6.022×10^{23} particles of that substance. The mass in grams of one mole of a substance is called its **molar mass**. Just as the mass of a dozen eggs is different from the mass of a dozen watermelons, different substances have different molar masses. The atomic mass of titanium (Ti), for example, is 47.87 amu, and the molar mass is 47.87 g/mol. By comparison, the atomic mass of sodium (Na) is 22.99 amu, and its molar mass is 22.99 g/mol. For a compound such as nitrogen dioxide (NO_2), the molar mass is the sum of the masses of its component atoms. The nitrogen dioxide (NO_2) molecule contains one nitrogen atom (1×14.01 amu) and two oxygen atoms (2×16.00 amu = 32.00 amu). So, NO_2 has a molar mass of 46.01 g/mol.

Given the mass of a substance, you can use the molar mass as a conversion factor to calculate the number of moles.

$$50.00 \text{ g } NO_2 \times \frac{1 \text{ mol } NO_2}{46.01 \text{ g } NO_2} = 1.087 \text{ mol } NO_2$$

Given the number of moles of a substance, you can use the molar mass as a conversion factor to calculate the mass.

$$0.2020 \text{ mol } NO_2 \times \frac{46.01 \text{ g } NO_2}{1 \text{ mol } NO_2} = 9.294 \text{ g } NO_2$$

Applying Math

12. Calculate What number goes in each indicated blank in the table?

Fe _____

Cl_2 _____

Cl_3 _____

After You Read

Mini Glossary

balanced chemical equation: having the same number of atoms of each element on both sides of an equation

chemical equation: a way to describe a chemical reaction using chemical formulas and other symbols

chemical reaction: a change in which one or more substances are converted into new substances

coefficient: a number that shows how many units of a substance take part in a reaction

molar mass: the mass of one mole of substance in grams

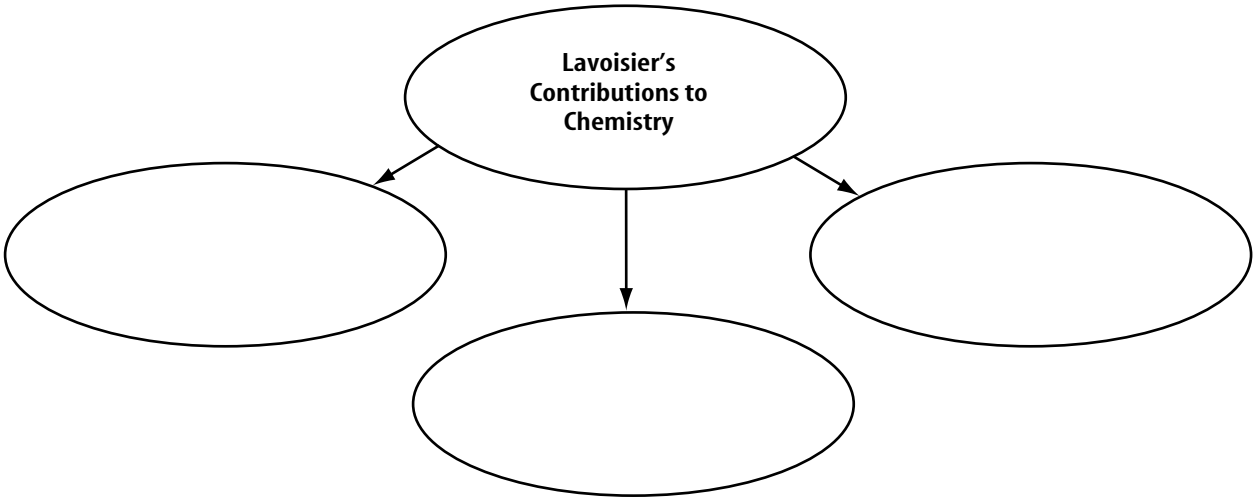
mole: 6.022×10^{23} number of particles of a substance

products: the new substances that are produced in a chemical reaction

reactants: the substances that react in a chemical reaction

1. Review the terms and their definitions in the Mini Glossary. Write a sentence describing a chemical equation.

2. Complete the concept web by writing three ways that Antoine Lavoisier helped to make chemistry into a modern science.



3. Study Coach You created a quiz with questions about important topics from the section. Which question was the hardest for you to answer? Why do you think this was?

End of Section