SECTION 8.1

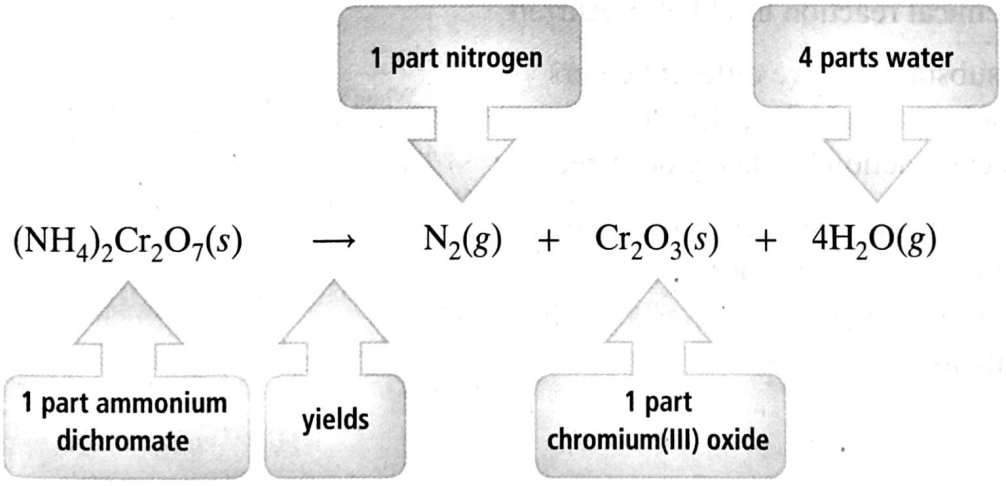
Describing Chemical Reactions

When iron rusts, oxygen combines with iron to make iron oxide. Iron and oxygen undergo a process called a chemical reaction. A chemical reaction is when one or more substances interact and produce one or more new substances. The original substances in a chemical reaction are called *reactants.* The new substances that are formed are called the *products.* In a chemical reaction, the total mass of the original reactants always equals the mass of the products. This is known as the law of conservation of mass.

KEY TERMS

chemical equation	word equation
precipitate	formula equation
coefficient	reversible reaction

Chemical reactions are described by chemical equations. A **chemical equation** is a way of showing the results of a chemical reaction using symbols and formulas. A chemical equation also shows the relative amounts of the reactants and products. For example, the chemical equation below shows that ammonium dichromate breaks down into nitrogen gas, chromium(III) oxide, and water.



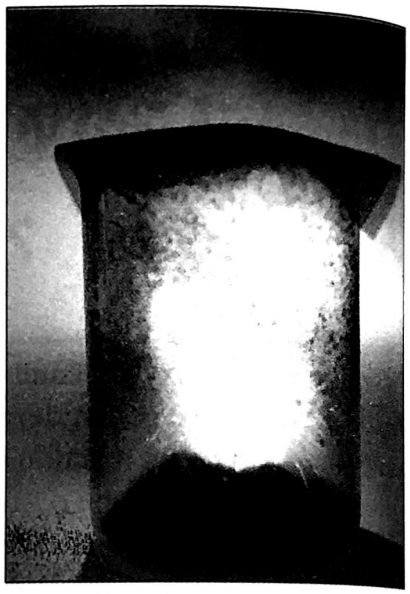
READING CHECK

1. In the chemical equation above, name the reactant(s) and product(s).

Chemical reactions have physical indicators.

The only way to really know that a chemical reaction has occurred is to analyze all the substances before and after the reaction. If the chemical identities of the reactants are different from those of the products, then you know a chemical reaction took place. There are, however, other changes that are easier to observe that often indicate a chemical reaction is taking place. Here are some of the common signs of a chemical reaction:

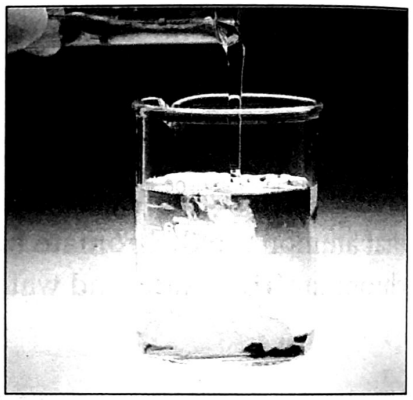
Energy Release When ammonium dichromate decomposes, it releases energy very quickly. This energy can be observed in the form of heat and light. Many chemical reactions release energy in the form of heat or light or both. However, the release of energy can also occur during a physical change, so other factors must also be considered to determine if a reaction did take place.



This ammonium dichromate reaction releases energy very quickly.

Gas Formation When vinegar is mixed with baking soda, bubbles of carbon dioxide gas form. The formation of a gas when two substances are mixed is a good indicator that the original substances are reacting.

Precipitate A **precipitate** is a solid that forms during a chemical reaction in a solution and separates from the solution. If a precipitate forms in a container after two substances are mixed, a chemical reaction has likely occurred.



When solutions of ammonium sulfide and cadmium nitrate are combined, the precipitate cadmium sulfide forms.

Color Change Often new substances have different colors from those of the original substances. If the color of a substance changes, a chemical reaction has likely occurred.

Observing these signs only means that a chemical change possibly occurred. Many of these signs also occur during a physical change. For example, boiling water creates a gas, but the gas has the same identity as the liquid.

READING CHECK

2. You mix two clear liquids and a colored solid forms at the bottom of the beaker. Do you think this is a chemical change? How can you know for certain?

Chemical equations must satisfy the law of conservation of mass.

A good chemical equation will tell you everything you need to know about a specific reaction. Here are the requirements for a good chemical equation:

1. **The equation must represent known facts.** It accurately shows all the reactants and products. These can be identified by experiments and chemical analysis, or by using reliable sources for information.
2. **The equation must contain the correct formulas for the reactants and products.** Remember what you have already learned about writing symbols and formulas. Know the oxidation states of the elements, as this will help you write correct formulas. Remember that some elements, such as oxygen and hydrogen, are usually diatomic molecules. Some of these elements are shown in the table below. If an element is not usually found in molecular form, just use the atomic symbol.
3. **The law of conservation of mass must be satisfied.** Atoms are not created or destroyed in a chemical reaction. Check to make sure you have the same numbers and types of atoms on both sides of your chemical equation.

In order to balance equations, add coefficients before each substance in an equation. A **coefficient** is a small whole number that goes in front of a formula in a chemical equation. It indicates the relative number of moles of a substance. For example, $3H_2O$ represents three moles of water molecules in a chemical equation.

Elements That Normally Exist as Diatomic Molecules

Element	Symbol	Molecular formula	Physical state at room temperature
Hydrogen	H	H_2	gas
Nitrogen	N	N_2	gas
Oxygen	O	O_2	gas
Fluorine	F	F_2	gas
Chlorine	Cl	Cl_2	gas
Bromine	Br	Br_2	liquid
Iodine	I	I_2	solid

READING CHECK

3. Why should the numbers and types of atoms be the same on both sides of your chemical equation?

_____

_____

_____

Critical Thinking

4. Apply Write a chemical formula that indicates two moles of chlorine molecules.

_____

Word and Formula Equations

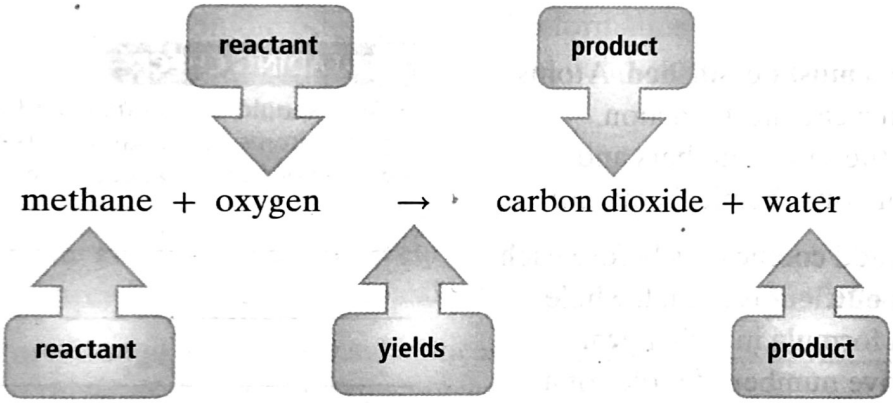
TIP Word equations are descriptions of a reaction. They do not tell you anything about the quantities of the substances.

1. The first step in writing a chemical equation is to identify the facts about a reaction that are known. It is often useful to represent these facts using a word equation. A **word equation** is an equation in which the reactants and products are written down in words.

   For example, when methane burns in air, it combines with oxygen to produce carbon dioxide and water vapor. To turn this information into a word equation, first identify the reactants and the products.

   REACTANTS: methane, oxygen
   PRODUCTS: carbon dioxide, water

   List the reactants on the left side of the equation and the products on the right side of the equation. Then draw an arrow pointing from the reactants to the products.



   The result is a word equation. This equation reads "methane and oxygen react to yield carbon dioxide and water."

PRACTICE

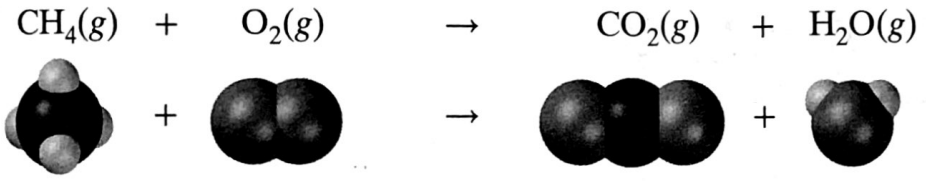
Write a word equation for each chemical reaction.

A. Solid calcium reacts with solid sulfur to produce solid calcium sulfide.

B. Hydrogen gas reacts with fluorine gas to produce hydrogen fluoride gas.

2. The next step in writing a chemical equation is to replace the words with the appropriate chemical formulas. A **formula equation** is an equation that uses chemical formulas and symbols to represent the reactants and products.

Consider the word equation from the previous page. Methane is a molecule that has one carbon atom and four hydrogen atoms. Its chemical formula is CH_4. Oxygen exists as a diatomic molecule, so its chemical formula is O_2. Carbon dioxide is CO_2 and water is H_2O. Therefore, the unbalanced formula equation is shown below:



The formula equation also includes information about the state of each substance in the reaction. For example, all four of the chemical formulas above indicate that the substances are in gaseous form during the reaction. A substance can be designated as a solid, as a liquid, as a gas, or as part of an aqueous solution.

The formula equation states the substances that are involved in the reaction. However, it still does not give any information about the relative quantities of the reactants and the products.

Remember

In a chemical formula, the state of the substance is shown in parentheses.

(*g*) is a gas

(*l*) is a liquid

(*s*) is a solid

(*aq*) is an aqueous solution, or a solution in water

PRACTICE

Write a formula equation for each of the following chemical reactions. Refer to the word equations you wrote on the previous page.

C. Solid calcium reacts with solid sulfur to produce solid calcium sulfide.

D. Hydrogen gas reacts with fluorine gas to produce hydrogen fluoride gas.

3. Look again at the formula equation for the reaction between methane and oxygen, shown below. In order to satisfy the conservation of mass, there should be an equal number of each type of atom on both sides of the equation.

$$CH_4(g) + O_2(g) \longrightarrow CO_2(g) + H_2O(g)$$

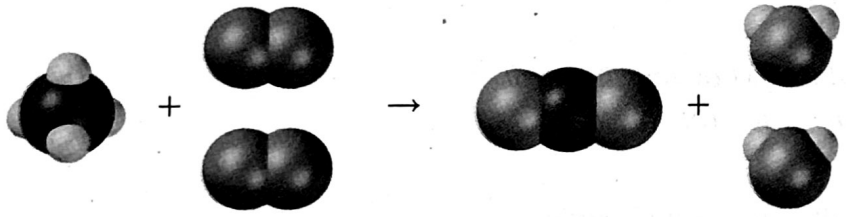
PRACTICE

E. Fill in the chart, showing the number of atoms on each side of the equation. The number of a given atom in each formula is equal to the product of the coefficient in front of the formula and the subscript on the atom.

UNBALANCED EQUATION		
Number of atoms of	**Reactants**	**Products**
carbon		
hydrogen		
oxygen		

Notice that the number of carbon atoms is the same on both sides. However, the numbers of hydrogen and oxygen atoms do not balance. We need to add coefficients to some of the formulas to make the equation balance. If we had two moles of oxygen on the reactant side, and two moles of water on the product side, the equation would be as follows.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$



This balanced equation is a chemical equation. It contains an accurate description of the reaction and tells you about the relative quantities of the reactants and the products. One mole of methane gas will react with two moles of molecular oxygen to form one mole of carbon dioxide gas and two moles of water vapor.

Critical Thinking

5. Evaluate Show that there are the same number of each type of atom on both sides of the balanced equation.

Additional Symbols Used in Chemical Equations

The table below shows some other symbols used in chemical equations. Some symbols may already be familiar to you.

Symbols Used in Chemical Equations

Symbol	Explanation
$\longrightarrow$	"Yields"; indicates result of reaction
$\rightleftharpoons$	Used in place of a single arrow to indicate a reversible reaction
(s)	A reactant or product in the solid state; also used to indicate a precipitate
$\downarrow$	Alternative to (s), but used only to indicate a precipitate
(l)	A reactant or product in the liquid state
(aq)	A reactant or product in an aqueous solution (dissolved in water)
(g)	A reactant or product in the gaseous state
$\uparrow$	Alternative to (g), but used only to indicate a gaseous product
$\xrightarrow{\Delta}$ or $\xrightarrow{\text{heat}}$	Reactants are heated
$\xrightarrow{2\text{ atm}}$	Pressure at which reaction is carried out, in this case 2 atm
$\xrightarrow{\text{pressure}}$	Pressure at which reaction is carried out exceeds normal atmospheric pressure
$\xrightarrow{0^\circ\text{C}}$	Temperature at which reaction is carried out, in this case 0°C
$\xrightarrow{MnO_2}$	Formula of catalyst, in this case manganese dioxide, used to alter the rate of the reaction

A reversible reaction is a chemical reaction in which the products re-form the original reactants. Not all reactions are reversible.

Some reactants must be heated for the reaction to take place.

For some reactions, it is important to show the temperature or pressure at which the reaction took place.

Some reactions can happen faster or at a lower temperature if a catalyst is present. A *catalyst* is a substance that has a temporary role in a chemical reaction, but is recovered unchanged when the reaction is complete.

Critical Thinking

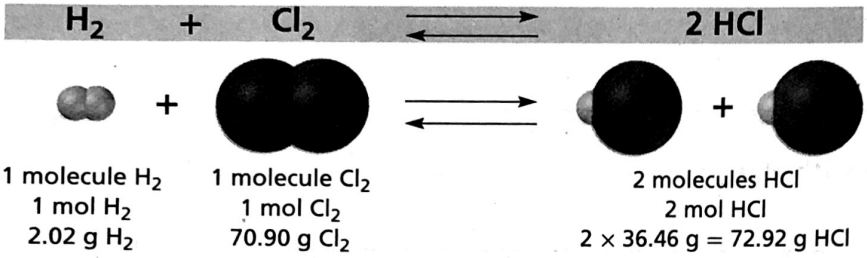
6. **Analyze** Write the following chemical equation as a descriptive sentence. Include all the information available in the equation.

$$2HgO(s) \xrightarrow{\Delta} 2Hg(l) + O_2(g)$$

Chemical equations show relative amounts, masses, and progression of chemical reactions.

When a chemical equation is balanced, it gives you a lot of information about the chemical reaction.

1. **The coefficients in a chemical equation tell you the relative, not absolute, amounts of the reactants and products.** The smallest units of matter that can undergo a chemical reaction are atoms, molecules, and ions. The law of conservation of mass determines how many of these small units are needed for a chemical reaction to take place.



For example, one molecule of hydrogen will react with one molecule of chlorine to form two molecules of hydrogen chloride. Similarly, one mole of hydrogen molecules will react with one mole of chlorine molecules to produce two moles of hydrogen chloride.

2. **The relative masses of the reactants and products of a chemical reaction can be determined from the reaction's coefficients.** When you have the relative amounts of the reactants and products, you can use these amounts to calculate the relative masses involved.

$$1 \cancel{\text{ mol } H_2} \cdot \frac{2.02 \text{ g } H_2}{1 \cancel{\text{ mol } H_2}} = 2.02 \text{ g } H_2$$

$$1 \cancel{\text{ mol } Cl_2} \cdot \frac{70.90 \text{ g } Cl_2}{1 \cancel{\text{ mol } Cl_2}} = 70.90 \text{ g } Cl_2$$

$$2 \cancel{\text{ mol HCl}} \cdot \frac{36.46 \text{ g HCl}}{1 \cancel{\text{ mol HCl}}} = 72.92 \text{ g HCl}$$

3. **The reverse reaction for a chemical equation has the same relative amounts of substances as the forward reaction.** Because a chemical equation is like an algebraic equation, the equality can be read in either direction. Two moles of hydrogen chloride will break down into one mole of molecular hydrogen gas and one mole of chlorine gas.

Remember

The arrow in a balanced chemical equation is like an equals sign in a mathematical equation. The coefficients tell you the relative amount of each substance.

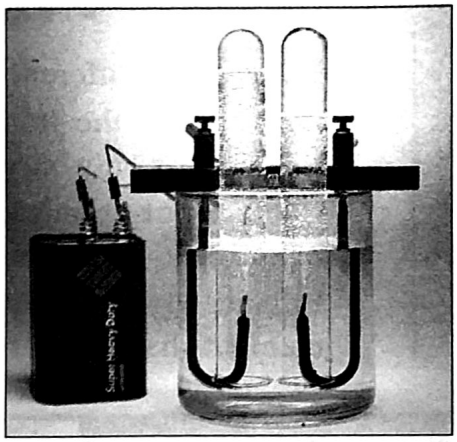
Critical Thinking

8. Apply Use the molar masses to show that mass was conserved in the reaction.

Chemical equations can be balanced with step-by-step inspection.

Sometimes it is easy to balance a chemical equation just by looking at it. Other times, you may need to use trial and error until you find the solution. There is a step-by-step process to help you balance equations.

Consider the reaction that occurs when electric current is passed through water, as shown in the photograph at the right. An electric current is passed through water that has been made slightly conductive. The water molecules break down to yield hydrogen in the right tube and oxygen in the left tube.



When an electric current is passed through impure water, oxygen gas bubbles into the left tube and hydrogen gas bubbles into the right tube.

1. **Identify the names of the reactants and the products, and write a word equation.**

   water → hydrogen + oxygen

2. **Write a formula equation by substituting correct formulas for the names of the reactants and the products.**

   $H_2O(l) \rightarrow H_2(g) + O_2(g)$ (not balanced)

TIP Remember to check for diatomic molecules when writing chemical formulas for elements.

3. **Balance the formula equation according to the law of conservation of mass.** In this equation, hydrogen appears to be balanced but oxygen is not. Determine the coefficient for the reactant that will bring the oxygen atoms into balance. Then determine if the hydrogen atoms can be balanced by adding a coefficient to the hydrogen gas product.

   $2H_2O(l) \rightarrow H_2(g) + O_2(g)$ (partially balanced)

   Balance the oxygen atoms first. You need 2 more on the left.

   $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$ (balanced)

   Next, balance the hydrogen atoms. You now need a total of 4 H on the right.

TIP Make sure that equal numbers of atoms of each element appear on both sides of the arrow in a balanced equation.

4. **Count atoms to be sure that the equation is balanced.**

   $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$

   $4H + 2O = 4H + 2O$ ✓

Problem-Solving TIPS

- Balance the different types of atoms one at a time.
- First balance the atoms of elements that are combined and that appear only once on each side of the equation.
- Balance polyatomic ions that appear on both sides of the equation as single units.
- Balance H atoms and O atoms after atoms of all other elements have been balanced.

SAMPLE PROBLEM

The reaction of zinc with aqueous hydrochloric acid produces a solution of zinc chloride and hydrogen gas. Write a balanced chemical equation for the reaction.

Zinc reacts with hydrochloric acid.

SOLUTION

1 ANALYZE *Write the word equation from the given information.*

zinc + hydrochloric acid → zinc chloride + hydrogen

2 PLAN *Write the formula equation that needs to be balanced.*

$Zn(s) + HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$ (not balanced)

3 SOLVE *Adjust the coefficients to balance the equation.*

Zinc is balanced. Next, look at chlorine. To balance chlorine, add a coefficient of 2 to HCl. Check hydrogen. Hydrogen is now also balanced. No more adjustments are needed.

$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$

4 CHECK YOUR WORK *Count atoms to check the balance.*

$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$

BALANCED EQUATION

Number of atoms of	Reactants	Products
zinc	1	1
chlorine	2	2
hydrogen	2	2

PRACTICE

1. Balance the following equation:

$Al_4C_3(s) + H_2O(l) \rightarrow CH_4(g) + Al(OH)_3(s)$

Start by balancing the aluminum atoms on each side.

How many are on the left? _____ on the right? _____

Now add the coefficient to $Al(OH)_3$ that balances the aluminum atoms:

$Al_4C_3(s) + H_2O(l) \rightarrow CH_4(g) + \square\ Al(OH)_3(s)$

Next, balance the carbon atoms.

How many are on the left? _____ on the right? _____

$Al_4C_3(s) + H_2O(l) \rightarrow \square\ CH_4(g) + \square\ Al(OH)_3(s)$

Now look at the oxygen atoms. The compound $Al(OH)_3$ has three oxygen atoms. Multiply this by the coefficient to determine the total number of oxygen atoms on the reactant side. Then balance these atoms by putting a coefficient by H_2O.

$Al_4C_3(s) + \square\ H_2O(l) \rightarrow \square\ CH_4(g) + \square\ Al(OH)_3(s)$

Finally, look at the hydrogen atoms.

How many are on the left? _____ on the right? _____

Write the balanced equation and check that it is balanced.

_____

BALANCED EQUATION		
Number of atoms of	**Reactants**	**Products**

SECTION 8.1 REVIEW

VOCABULARY

1. Describe the differences between word equations, formula equations, and chemical equations.

REVIEW

2. List three signs that indicate a chemical reaction has probably taken place.

3. Translate the following chemical equation into a sentence:

$2K(s) + 2H_2O(l) \rightarrow 2KOH(aq) + H_2(g)$

4. Write the word, formula, and chemical equations for the reaction between hydrogen sulfide gas and oxygen gas that produces sulfur dioxide gas and water vapor.

Critical Thinking

5. INTEGRATING CONCEPTS The reaction of vanadium(II) oxide with iron(III) oxide results in the formation of vanadium(V) oxide and iron(II) oxide. Write the balanced chemical equation for the reaction.

Word Equation:

Formula Equation:

Balanced Chemical Equation: