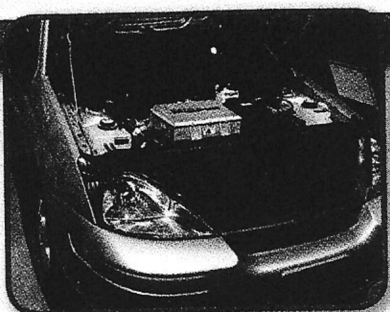
Lessons 4 + 5

Describing Chemical Reactions



CHEMISTRY & YOU

Q: *How is a chemical reaction going to change the way you drive?* You've probably heard about hydrogen fuel-cell cars. Fuel cells produce electricity through a chemical reaction without any of the combustion that you find in typical gasoline engines. In this lesson, you'll learn how to write and balance the equations that represent chemical reactions.

Key Questions

How do you write a skeleton equation?

What are the steps for writing and balancing a chemical equation?

Vocabulary

- chemical equation
- skeleton equation
- catalyst
- coefficient
- balanced equation

Lesson 4 -

Introduction to Chemical Equations

How do you write a skeleton equation?

Every minute of the day chemical reactions take place—both inside you and around you. After a meal, a series of chemical reactions take place as your body digests food. Similarly, plants use sunlight to drive the photosynthetic processes needed to produce plant growth. Although the chemical reactions involved in photosynthesis and digestion are different, both chemical reactions are necessary to sustain life. All chemical reactions, whether simple or complex, involve changing substances.

In a chemical reaction, one or more reactants change into one or more products. Cooking food always involves a chemical reaction. In order to bake muffins, you begin with a recipe and ingredients, as shown in Figure 4A. The recipe tells you which ingredients to mix together and how much of each to use. Chemical reactions take place when the ingredients or reactants are mixed together and heated in the oven. The product, in this case, is a batch of muffins. Chemists use a chemical equation—a quick, shorthand notation—to convey as much information as possible about what happens in a chemical reaction.

Figure 4A
Reactants and Products
Reactants in the ingredients undergo chemical changes to form the product, the muffins.
Observing ***What evidence shows that chemical changes have occurred?***

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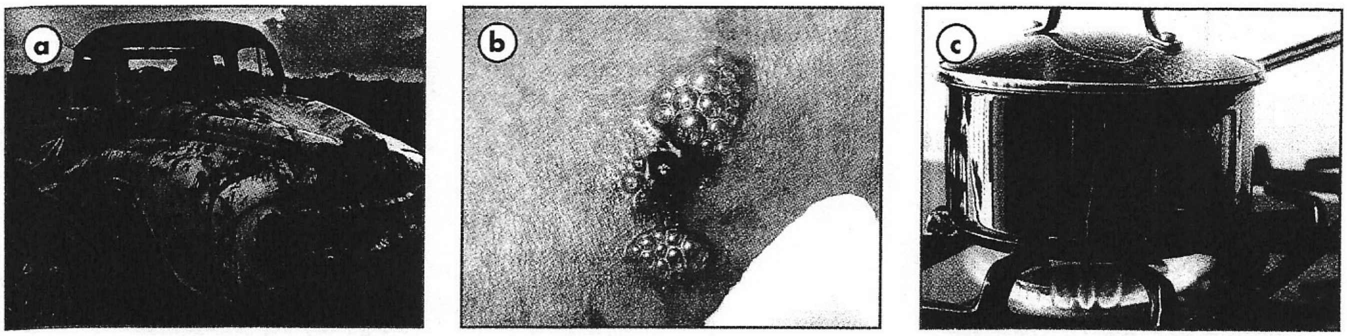
Figure 4B Examples of Reactions
Three common chemical reactions are shown below.



(a) Iron turns to red-brown rust (iron(III) oxide) in the presence of oxygen.

(b) Water and oxygen form when hydrogen peroxide is poured on a cut.

(c) The products of burning methane are carbon dioxide and water.

Word Equations How do you describe what happens in a chemical reaction? Seen below, the shorthand method for writing a description of a chemical reaction. In this method, the reactants are written on the left and the products on the right. An arrow separates them. You read the arrow as *yields, gives,* or *reacts to produce.*

$$\text{Reactants} \longrightarrow \text{products}$$

How could you describe the rusting of iron shown in Figure 4B(a)? You could say: "Iron reacts with oxygen to produce iron(III) oxide (rust)." Although that is a perfectly good description, it's quicker to identify the reactants and product by means of a word equation.

$$\text{Iron} + \text{oxygen} \longrightarrow \text{iron(III) oxide}$$

In a word equation, write the names of the reactants to the left of the arrow, separated by plus signs; write the names of the products to the right of the arrow, also separated by plus signs. Notice that no plus sign is needed on the product side of this equation because iron(III) oxide is the only product.

Have you ever poured the antiseptic hydrogen peroxide on an open cut? Bubbles of oxygen gas form rapidly, as shown in Figure 4B(b). The production of a new substance, a gas, is evidence of a chemical change. Two new substances are produced in this reaction, oxygen gas and liquid water. You could describe this reaction by saying, "Hydrogen peroxide decomposes to form water and oxygen gas." But, you could also write a word equation.

$$\text{Hydrogen peroxide} \longrightarrow \text{water} + \text{oxygen}$$

When you light a burner on your stove, methane gas bursts into flames and produces the energy needed to heat your soup. Methane is the major component of natural gas, a common fuel for heating homes and cooking food. The burning of methane, as shown in Figure 4B(c), is a chemical reaction. How would you write the word equation for this reaction? Burning a substance typically requires oxygen, so methane and oxygen are the reactants. The products are water and carbon dioxide. Thus, the word equation is as follows:

$$\text{Methane} + \text{oxygen} \longrightarrow \text{carbon dioxide} + \text{water}$$

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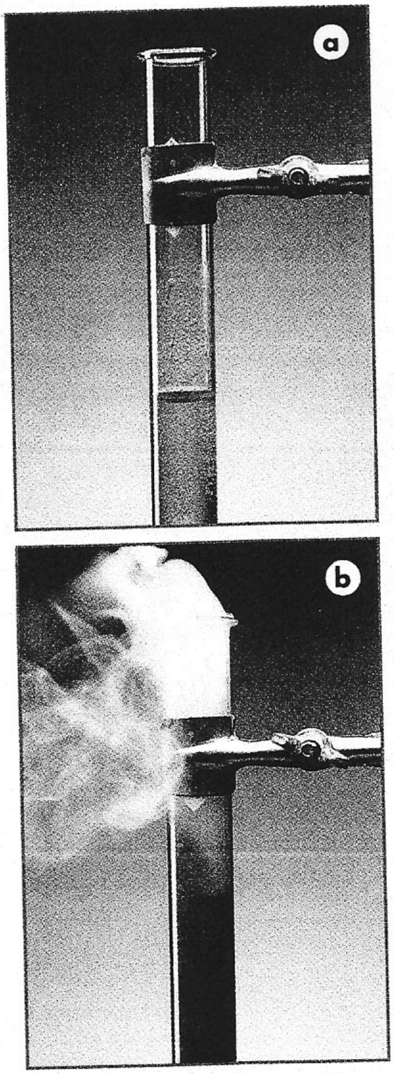

Figure 4C
Speeding Up a Reaction
Hydrogen peroxide decomposes to form water and oxygen gas. **a.** Bubbles of oxygen appear slowly as decomposition proceeds. **b.** With the addition of the catalyst manganese(IV) oxide (MnO_2), decomposition speeds up. The white "smoke" is condensed water vapor.

Chemical Equations Word equations adequately describe chemical reactions, but they are cumbersome. It's easier to use the formulas for the reactants and products to write chemical equations. A **chemical equation** is a representation of a chemical reaction; the formulas of the reactants (on the left) are connected by an arrow with the formulas of the products (on the right). Here is a chemical equation for rusting:

$$Fe + O_2 \longrightarrow Fe_2O_3$$

Equations that show just the formulas of the reactants and products are called skeleton equations. A **skeleton equation** is a chemical equation that does not indicate the relative amounts of the reactants and products. The first step in writing a complete chemical equation is to write the skeleton equation. **To write a skeleton equation, write the chemical formulas for the reactants to the left of the yields sign (arrow) and the formulas for the products to the right.**

To add more information to the equation, you can indicate the physical states of substances by putting a symbol after each formula. Use (*s*) for a solid, (*l*) for a liquid, (*g*) for a gas, and (*aq*) for a substance in aqueous solution (a substance dissolved in water). Here is the unbalanced equation for rusting with symbols for the physical states added:

$$Fe(s) + O_2(g) \longrightarrow Fe_2O_3(s)$$

In many chemical reactions, a catalyst is added to the reaction mixture. A **catalyst** is a substance that speeds up the reaction but is not used up in the reaction. A catalyst is neither a reactant nor a product, so its formula is written above the arrow in a chemical equation. For example, Figure 4C shows that the compound manganese(IV) oxide ($MnO_2(s)$) catalyzes the decomposition of an aqueous solution of hydrogen peroxide ($H_2O_2(aq)$) to produce water and oxygen.

$$H_2O_2(aq) \xrightarrow{MnO_2} H_2O(l) + O_2(g)$$

Many of the symbols commonly used in writing chemical equations are listed below.

Table 4.1

Symbols Used in Chemical Equations

Symbol	Explanation
$+$	Separates two reactants or two products
$\longrightarrow$	"Yields," separates reactants from products
$\rightleftharpoons$	Used in place of $\longrightarrow$ for reversible reactions
(*s*), (*l*), (*g*)	Designates a reactant or product in the solid state, liquid state, and gaseous state; placed after the formula
(*aq*)	Designates an aqueous solution; the substance is dissolved in water; placed after the formula
$\xrightarrow{\Delta}$ $\xrightarrow{heat}$	Indicates that heat is supplied to the reaction
$\xrightarrow{Pt}$	A formula written above or below the yield sign indicates its use as a catalyst (in this example, platinum).

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SampleProblem 4.1

Writing a Skeleton Equation

Hydrochloric acid reacts with solid sodium hydrogen carbonate. The products formed are aqueous sodium chloride, water, and carbon dioxide gas. Write a skeleton equation for this chemical reaction.

1 Analyze Identify the relevant concepts.
Write the correct formula for each substance in the reaction. Indicate the state of each substance. Separate the reactants from the products with an arrow. Use plus signs to separate the two reactants and each of the three products.

2 Solve Apply concepts to this problem.

Start with the names of reactants and products. Include their physical states.

Reactants
sodium hydrogen carbonate (solid)
hydrochloric acid (aqueous)

Products
sodium chloride (aqueous)
water (liquid)
carbon dioxide (gas)

Write the correct formula for each reactant and each product.

Reactants
$NaHCO_3(s)$ $HCl(aq)$

Products
$NaCl(aq)$ $H_2O(l)$ $CO_2(g)$

Separate the reactants from the products with an arrow. Use plus signs to separate the reactants and the products.

$NaHCO_3(s) + HCl(aq) \longrightarrow NaCl(aq) + H_2O(l) + CO_2(g)$

I. Write a sentence that describes this chemical reaction:
$Na(s) + H_2O(l) \longrightarrow NaOH(aq) + H_2(g)$

II. Sulfur burns in oxygen to form sulfur dioxide. Write a skeleton equation for this chemical reaction.

Balancing Chemical Equations – Lesson 5

What are the steps for writing and balancing a chemical equation?

How would you write a word equation for the manufacture of bicycles? Simplify your task by limiting yourself to four major components: frames, wheels, handlebars, and pedals. Your word equation for making a bicycle could read like this.

$$\underbrace{\text{Frame} + \text{wheel} + \text{handlebar} + \text{pedal}}_{\text{Reactants}} \longrightarrow \underbrace{\text{bicycle}}_{\text{Product}}$$

Your word equation shows the reactants (the kinds of parts) and the product (a bicycle).

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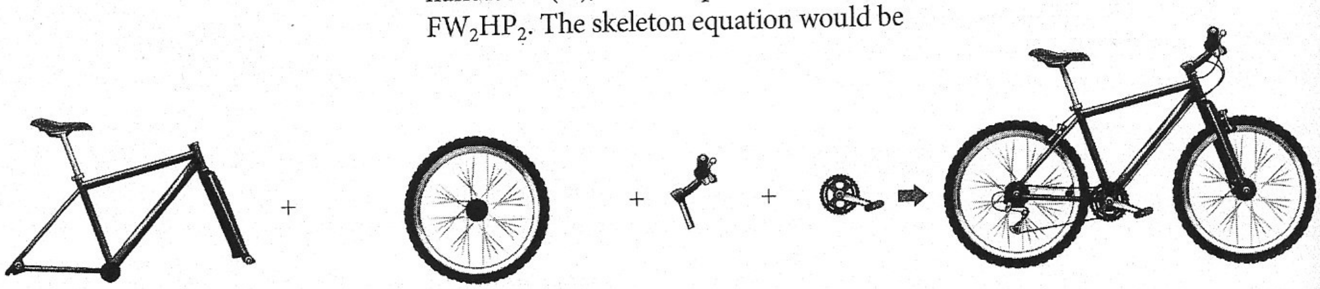
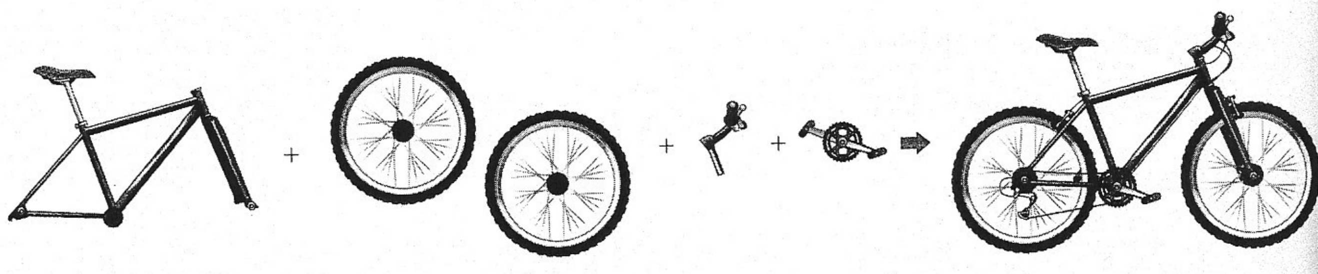
But if you were responsible for ordering parts to make a bicycle, this word equation would be inadequate because it does not indicate the quantity of each part needed to make one bicycle.

A standard bicycle is composed of one frame (F), two wheels (W), one handlebar (H), and two pedals (P). The formula for a bicycle would be FW_2HP_2. The skeleton equation would be



$$F + 1W + H + 1P \longrightarrow FW_2HP_2$$

This equation is unbalanced. An unbalanced equation does not indicate the quantity of the reactants needed to make the product. A complete description of the reaction must include not only the kinds of parts involved but also the quantities of parts required.



$$F + 2W + H + 2P \longrightarrow FW_2HP_2$$

This equation for making a bicycle is balanced. It tells you that one frame, two wheels, one handlebar, and two pedals produce one bicycle. To balance the equation, the number 2 was placed before wheels and pedals. The number 1 is understood to be in front of *frame, handlebar,* and *bicycle.* These numbers are called **coefficients**—small whole numbers that are placed in front of the formulas in an equation in order to balance it. In this balanced equation, the number of each bicycle part on the reactant side is the same as the number of those parts on the product side. A chemical reaction is also described by a **balanced equation** in which each side of the equation has the same number of atoms of each element and mass is conserved.

Recall that John Dalton's atomic theory states that as reactants are converted to products, the bonds holding the atoms together are broken, and new bonds are formed. The atoms themselves are neither created nor destroyed; they are merely rearranged.

This part of Dalton's theory explains the law of conservation of mass. In any chemical change, mass is conserved. The atoms in the products are the same atoms that were in the reactants—they are just rearranged. Representing a chemical reaction by a balanced chemical equation is a two-step process. **To write a balanced chemical equation, first write the skeleton equation. Then use coefficients to balance the equation so that it obeys the law of conservation of mass.** In every balanced equation, each side of the equation has the same number of atoms of each element.

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Sometimes, though, a skeleton equation may already be balanced. For example, carbon burns in the presence of oxygen to produce carbon dioxide.

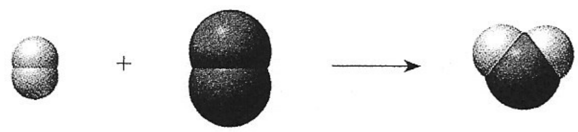
$C(s)$ + $O_2(g)$ ⟶ $CO_2(g)$
Carbon + Oxygen ⟶ Carbon Dioxide

Reactants
1 carbon atom, 2 oxygen atoms

Product
1 carbon atom, 2 oxygen atoms

This equation is balanced. One carbon atom and two oxygen atoms are on each side of the equation. You do not need to change the coefficients; they are all understood to be 1.

What about the equation for the reaction of hydrogen and oxygen gas? When hydrogen and oxygen are mixed, the product of the reaction is water. The skeleton equation is as follows:



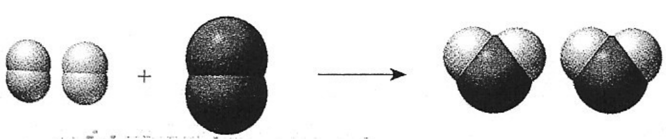
$H_2(g)$ + $O_2(g)$ ⟶ $H_2O(l)$
Hydrogen + Oxygen ⟶ Water

Reactants
2 hydrogen atoms
2 oxygen atoms

Product
2 hydrogen atoms
1 oxygen atom

The formulas for all the reactants and the product are correct, but this equation is not balanced. Count the atoms on both sides of the equation. Two oxygen atoms are on the reactant (left) side of the equation and only one oxygen atom is on the product (right) side. As written, the equation does not obey the law of conservation of mass, and so it does not describe quantitatively what really happens. What can you do to balance it?

To balance the equation for the reaction of hydrogen and oxygen, count the number of each kind of atom. Hydrogen is balanced, but oxygen is not. If you put the coefficient 2 in front of H_2O, the oxygen will be balanced. Now twice as many hydrogen atoms are in the product as are in the reactants. To correct this equation, put the coefficient 2 in front of H_2. Four hydrogen atoms and two oxygen atoms are on each side of the chemical equation. The equation is now balanced.



$2H_2(g)$ + $O_2(g)$ ⟶ $2H_2O(l)$
Hydrogen + Oxygen ⟶ Water

Reactants
4 hydrogen atoms
2 oxygen atoms

Products
4 hydrogen atoms
2 oxygen atoms

A few guidelines for writing and balancing equations are in the table on the next page.

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Q: *The reaction between oxygen and hydrogen in fuel cells produce the energy to power a car. What are the products of the reaction in a fuel cell that make the fuel-cell car a zero-emission car?*

See balancing equations *animated* online. KINETIC ART

Lesson 5

Rules for Writing and Balancing Equations

1. Determine the correct formulas for all the reactants and products.
2. Write the skeleton equation by placing the formulas for the reactants on the left and the formulas for the products on the right with a yields sign ($\longrightarrow$) in between. If two or more reactants or products are involved, separate their formulas with plus signs.
3. Determine the number of atoms of each element in the reactants and products. Count a polyatomic ion as a single unit if it appears unchanged on both sides of the equation.
4. Balance the elements one at a time by using coefficients. When no coefficient is written, it is assumed to be 1. Begin by balancing elements that appear only once on each side of the equation. Never balance an equation by changing the subscripts in a chemical formula. Each substance has only one correct formula.
5. Check each atom or polyatomic ion to be sure that the number is equal on both sides of the equation.
6. Make sure all the coefficients are in the lowest possible ratio.

CHEM TUTOR

Sample Problem 5.1

Balancing a Chemical Equation

Students suspended copper wire in an aqueous solution of silver nitrate. They noticed a deposit of silver crystals on the copper wire when the copper reacted with the silver nitrate. They recorded the equation for this reaction but didn't balance it. Balance their equation.

$$AgNO_3(aq) + Cu(s) \longrightarrow Cu(NO_3)_2(aq) + Ag(s)$$

1 Analyze Identify the relevant concepts.
Apply the rules for balancing equations. Because the nitrate polyatomic ion appears as a reactant and a product, this ion can be balanced as a unit.

Remember that a coefficient must always go in front of a compound's formula, not in the middle of it.

2 Solve Apply concepts to this problem.

Balance the nitrate ion. Put a coefficient 2 in front of $AgNO_3(aq)$.

$$2AgNO_3(aq) + Cu(s) \longrightarrow Cu(NO_3)_2(aq) + Ag(s)$$

Balance the silver. Put a coefficient 2 in front of Ag(s).

$$2AgNO_3(aq) + Cu(s) \longrightarrow Cu(NO_3)_2(aq) + 2Ag(s)$$

I. Balance the equation:
$CO + Fe_2O_3 \longrightarrow Fe + CO_2$

II. Write the balanced chemical equation for the reaction of carbon with oxygen to form carbon monoxide.

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Sample Problem S.2

Balancing a Chemical Equation

Aluminum is a good choice for outdoor furniture because it reacts with oxygen in the air to form a thin protective coat of aluminum oxide. Balance the equation for this reaction.

$$Al(s) + O_2(g) \longrightarrow Al_2O_3(s)$$

1 Analyze Identify the relevant concepts.
Apply the rules for balancing equations. Notice the odd number of oxygen atoms in the product.

2 Solve Apply concepts to this problem.

First balance the aluminum by placing the coefficient 2 in front of Al(s).

$$2Al(s) + O_2(g) \longrightarrow Al_2O_3(s)$$

Any whole number coefficient placed in front of O_2 will always give an even number of oxygen atoms on the left.

Multiply the formula with the odd number of oxygen atoms (on the right) by 2 to get an even number of oxygen atoms on the right.

$$2Al(s) + O_2(g) \longrightarrow 2Al_2O_3(s)$$

Balance the oxygens on the left by placing a 3 in front of O_2.

$$2Al(s) + 3O_2(g) \longrightarrow 2Al_2O_3(s)$$

Then rebalance the aluminum by changing the coefficient of Al(s) from 2 to 4.

$$4Al(s) + 3O_2(g) \longrightarrow 2Al_2O_3(s)$$

10 Balance each equation.

a. $FeCl_3 + NaOH \longrightarrow Fe(OH)_3 + NaCl$

b. $CS_2 + Cl_2 \longrightarrow CCl_4 + S_2Cl_2$

c. $KI + Pb(NO_3)_2 \longrightarrow PbI_2 + KNO_3$

d. $C_2H_2 + O_2 \longrightarrow CO_2 + H_2O$

11 Write and balance these equations.

a. calcium hydroxide + sulfuric acid ⟶ calcium sulfate + water

b. sodium + water ⟶ sodium hydroxide + hydrogen