# CHAPTER 6

# Chemical Reactions: An Introduction

## INTRODUCTION

Knowing how to write chemical equations and how to interpret what they mean is an important part of chemistry. If you have learned the symbols for the elements and can write the formulas of compounds from their names, then learning to write chemical equations will be easier. The Answers to Learning Review (#5) discusses the logic used when balancing a chemical equation by trial and error. If you are having trouble balancing equations, go over the steps used to balance the equations in the Answers to Learning Review.

## CHAPTER DISCUSSION

You have already seen a molecular level representation of a balanced chemical equation in Chapter 4 (see Figure 4.15). Another such representation of a different chemical equation can be seen in Figure 6.4.

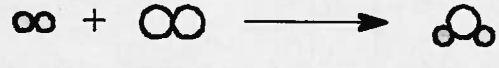
Remember that the point of a chemical equation is to use symbols to show what happens during the chemical reaction. Therefore, while you are first learning to balance chemical equations it is a good idea to think at a molecular level to make sure you are balancing the equation and not changing the composition of a reactant or a product. Learn to relate the words to the representation (molecular level perspective) to the symbols (the coefficients, subscripts, and atomic symbols).

For example, consider the statement,

"Hydrogen gas reacts with oxygen gas to produce water vapor."

We would like to write this reaction as an equation in terms of the symbols for the elements. What is the advantage to this? First, it is generally easier to write once you understand the language. But more importantly, using the symbols allows us to balance the equation, which means we are able to determine the relative amounts of the reactants we need (in this case hydrogen gas and oxygen gas) along with the relative amount of product produced (in this case, the water).

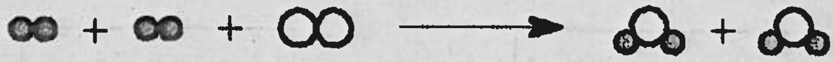
Let's look at the reaction statement in terms of a molecular-level sketch. To do this, we have to know the formulas for hydrogen gas, oxygen gas, and water and how to sketch them. Recall that hydrogen and oxygen gases are diatomic (two atoms per molecule) and that the water molecule consists of two hydrogen atoms and one oxygen atom. Thus, we can sketch a representation of the reaction as follows:



While this conveys what occurs, it is not balanced. That is, it does not give us information about the relative amounts of reactants and products. Notice, for example, that there are two oxygen atoms on the left side of the equation and only one oxygen atom on the right side. This simply cannot occur during a chemical reaction.

Because oxygen gas is diatomic, and water consists of only one oxygen atom, a diatomic oxygen molecule can produce two molecules of water.

**However, one hydrogen molecule can produce only one molecule of water. To produce two molecules of water would require two molecules of hydrogen gas.**



**This equation is now balanced. All atoms are accounted for on each side of the equation; that is, all atoms are conserved.**

**Now we are ready to think about this sketch in terms of chemical symbols. We have four atoms of hydrogen and two atoms of oxygen on each side of the equation, but we also want to convey that hydrogen gas is reacting with oxygen gas to form water. In fact, now that we have balanced our equation, we can be more specific about the amounts and state the reaction as,**

> **"Two molecules of hydrogen gas react with one molecule of oxygen gas to produce two molecules of water."**

**We can symbolize the diatomic hydrogen gas as $H_2$, the diatomic oxygen gas as $O_2$, and water as $H_2O$. We have balanced the equation with our molecular level sketches, so now we can add these numbers to our equation to get**

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

**Note there is a 2:1:2 ratio of molecules just as we determined with the molecular-level sketches (we generally do not include the "1" in front of a molecule–it is assumed). These numbers are called the coefficients and represent the ratio of molecules (reactants and products) in the equation. Recall from Chapter 4 that the subscripts in the molecules tell us how many atoms of a particular element are in one molecule.**

**One common mistake made when first balancing equations is to change subscripts. For example, if we look at the unbalanced equation,**

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

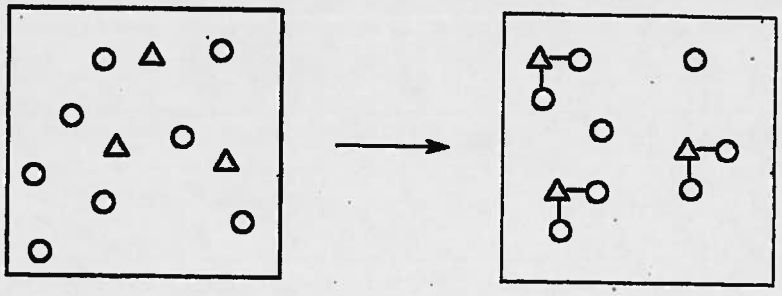
**it may seem reasonable to balance this equation by adding another oxygen atom to the water molecule to get**

$$2H_2(g) + O_2(g) \rightarrow 2H_2O_2\,(l).$$

**What is wrong with this? Think back to our molecular level drawings and how you would sketch $H_2O$ compared to $H_2O_2$. They are different molecules with different chemical properties. Changing the subscript changes the identity of the chemical. In this case, for example, $H_2O_2$ is hydrogen peroxide which is quite different from water. The goal to balancing a chemical equation is not to just make sure there are the same numbers of each type of atom on both sides of the equation, but to balance the equation that is given to you. In this case we wanted to balance the equation that represented the production of water, not hydrogen peroxide.**

**For another example, answer the following question (think about it before reading on).**

The reaction of an element X (Δ) with element Y (O) is represented in the following diagram. Which of the equations best describes this reaction?



a. $3X + 8Y \rightarrow X_3Y_8$

b. $3X + 6Y \rightarrow X_3Y_6$

c. $X + 2Y \rightarrow XY_2$

d. $3 + 8Y \rightarrow 3XY_2 + 2Y$

e. $X + 4Y \rightarrow XY_2$

The correct answer is "c". Choices "a" and "b" give the wrong products. The product formed should be symbolized as "$XY_2$" from the molecular drawing. Choices "c," "d," and "e" have this as a product, but choice "e" is not balanced. So what is wrong with choice "d"? Many students choose this because it correctly gives the number of X's and Y's on the reactant side and shows that there are two Y's left over when the reaction is completed. So why is it incorrect?

First of all, the chemicals on the right side of the equation are the products, that is, they are produced in the reaction. If choice "d" is correct, this implies that Y's were produced in this reaction, and this is not true; that is, Y's may be left over, but they were not made. Also, the fact that we started with three X's and eight Y's is not relevant in this case. The balanced equation does not (repeat, does **not**) tell us how much of each chemical we have, but it gives us a ratio of the amounts that react or are produced. Think of it in terms of a recipe. A recipe is written to tell you how much of each ingredient is needed to react with the others in order to make a certain amount of product. It does not tell you how much of each ingredient you happen to have in your kitchen. Thus, choice "c" tells us what is actually reacting; that is, for every one X, two Y's react to form one $XY_2$.

Could we symbolize the reaction the following way?

$$2X + 4Y \rightarrow 2XY_2$$

Yes we could. However, we generally reduce all of the coefficients to the least common whole numbers for the sake of simplicity. This brings up an important point; the value of an individual coefficient is not important. What is important is the ratio of the coefficients.

Suppose, for example, you want a recipe for chocolate chip cookies, and you are told that you will need flour, sugar, eggs, baking soda, salt, and one egg. Telling you that you need one egg is not very helpful since you don't know the amounts of the other ingredients nor do you know how many cookies it will make. And realize that even if you are told all the amounts, you can change them to make the number of cookies you want. Thus the actual numbers are not as important as the ratio.

For example, recall the balanced equation

$$2H_2 + O_2 \rightarrow 2H_2O$$

This equation can be read as,

"Two molecules of diatomic hydrogen react with one molecule of diatomic oxygen to produce two molecules of water"

or

"Two dozen molecules of diatomic hydrogen react with one dozen molecules of diatomic oxygen to produce two dozen molecules of water"

or

"Two hundred molecules of diatomic hydrogen react with 100 molecules of diatomic oxygen to produce 200 molecules of water."

In fact, there are an infinite number of possibilities as long as the ratio of the number of molecules of $H_2$, $O_2$ and $H_2O$ is 2:1:2, respectively.

Again, the individual coefficient is not important. It is the ratio between reactants and products that is important.

Finally, while you are first balancing equations you may wish to use molecular-level drawings, but you should eventually work toward writing an equation (and then balancing it) using symbols directly from the words. There are many examples of these types of questions at the end of Chapter 6 in your text.

## LEARNING REVIEW

1. Which of the following indicates that a chemical reaction has occurred?
   a. Liquid water boils to produce steam.
   b. Burning firewood gives off heat.
   c. Mixing two colorless liquids produces a bright yellow solid.
   d. Solid $NaHCO_3$ dissolves in water.
2. Why is it important that chemical equations be balanced?
3. Count the number of each kind of atom on both sides of the equation, and decide which reactions are balanced and which are not.
   a. $H_2 + Br_2 \rightarrow HBr$
   b. $KClO_3 \rightarrow KCl + O_2$
   c. $2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$
   d. $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$
   e. $3Cu + HNO_3 \rightarrow 3Cu(NO_3)_2 + NO + H_2O$
4. Use the following word descriptions to write unbalanced chemical equations showing the formulas of reactants and products. Make sure you include the physical states of reactants and products.
   a. Solid iron metal reacts with oxygen in the atmosphere to form rust, iron(III) oxide.
   b. Solid magnesium metal reacts with aqueous hydrochloric acid to produce hydrogen gas and an aqueous solution of magnesium chloride.
   c. Solid silver oxide decomposes upon heating to produce solid silver metal and oxygen gas.
   d. Aqueous sodium hydroxide reacts with aqueous nitric acid to produce aqueous sodium nitrate and liquid water.

5. Balance these chemical equations. Check your work by counting the number of each kind of atom on both sides of the equation.

   a. $KOH(aq) + H_2S(aq) \rightarrow K_2S(aq) + H_2O(l)$

   b. $HNO_2(aq) \rightarrow N_2O_3(g) + H_2O(aq)$

   c. $NaOH(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + H_2O(l)$

   d. $(NH_4)_2S(aq) + Pb(NO_3)_2(aq) \rightarrow PbS(s) + NH_4NO_3(aq)$

   e. $Al(s) + O_2(g) \rightarrow Al_2O_3(s)$

6. Balance these chemical equations.

   a. $SO_2(g) + O_2(g) \rightarrow SO_3(g)$

   b. $C_4H_{10}(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$

   c. $Fe_2O_3(s) + C(s) \rightarrow Fe(s) + CO_2(g)$

   d. $TiCl_4(l) + H_2O(l) \rightarrow TiO_2(s) + HCl(aq)$

7. Balance these chemical equations.

   a. $KI(aq) + Br_2(l) \rightarrow KBr(aq) + I_2(s)$

   b. $PbO_2(s) \rightarrow PbO(s) + O_2(g)$

   c. $Fe(OH)_3(s) + H_2SO_4(aq) \rightarrow Fe_2(SO_4)_3(s) + H_2O(l)$

   d. $K_3PO_4(aq) + BaCl_2(aq) \rightarrow KCl(aq) + Ba_3(PO_4)_2(s)$

## ANSWERS TO LEARNING REVIEW

1.

   a. Boiling represents a physical change; not a chemical reaction.

   b. Heat production is an indication of a chemical reaction.

   c. A color change and the production of a solid (a new substance) are both indications of a chemical reaction.

   d. No chemical reaction has occurred. Solid $NaHCO_3$ dissolves into ions in water. The ions are so small they cannot be seen, but the identity of the compound does not change.

2. When a chemical reaction occurs, atoms are neither created nor destroyed. The atoms are only rearranged to produce new molecules. Therefore it is important that the same kinds and numbers of atoms be present on both sides of a chemical equation.

| | | | |
|---|---|---|---|
| $H_2 + Br_2$ | $\rightarrow$ | HBr | |
| 2 H | | 1 H | |
| 2 Br | | 1 Br | unbalanced |

3.

   a.

| | | | |
|---|---|---|---|
| $KClO_3$ | $\rightarrow$ | $KCl + O_2$ | |
| 1 K | | 1 K | |
| 1 Cl | | 1 Cl | |
| 3 O | | 2 O | unbalanced |

b.

| $2NaOH + CO_2$ | → | $Na_2CO_3 + H_2O$ | |
|---|---|---|---|
| 2 Na | | 2 Na | |
| 2 O | | 1 C | |
| 2 H | | 3 O | |
| 1 C | | 2 H | |
| 2 O | | 1 O | |
| The **total** number of atoms of each kind is | | | |
| 2 Na | | 2 Na | |
| 4 O | | 4 O | |
| 2 H | | 2 H | |
| 1 C | | 1 C | balanced |

c.

| $C_2H_5OH + 3O_2$ | → | $2CO_2 + 3H_2O$ | |
|---|---|---|---|
| 2 C | | 2 C | |
| (5 + 1) H | | (2 × 2) O | |
| 1 O | | (3 × 2) H | |
| (3 × 2) O | | 3 O | |
| The **total** number of atoms of each kind is | | | |
| 2 C | | 2 C | |
| 6 H | | 6 H | |
| 7 O | | 7 O | balanced |

d.

| $3Cu + HNO_3$ | → | $3Cu(NO_3)_2 +$ $NO + H_2O$ | |
|---|---|---|---|
| 3 Cu | | 3 Cu | |
| 1 H | | (3 × 2) O | |
| 1 N | | 2 N | |
| 3 O | | 1 N | |
| | | 1 O | |
| | | 2 H | |
| | | 1 O | |
| The **total** number of atoms of each kind is | | | |
| 3 Cu | | 3 Cu | |
| 1 H | | 2 H | |
| 1 N | | 3 N | |
| 3 O | | 8 O | unbalanced |

4. This problem requires that you be able to write formulas from word descriptions. Do not forget to include the physical state of both products and reactants.

a. $Fe(s) + O_2(g) \rightarrow Fe_2O_3(s)$

b. $Mg(s) + HCl(aq) \rightarrow H_2(g) + MgCl_2(aq)$

c. $Ag_2O(s) \rightarrow Ag(s) + O_2(g)$

d. $NaOH(aq) + HNO_3(aq) \rightarrow NaNO_3(aq) + H_2O(l)$

5.

a. First find the most complex formula. KOH contains three different kinds of atoms, so begin by adjusting the coefficients of the atoms in KOH. There are two potassium atoms on the right and only one on the left. Adjust potassium by increasing the coefficient of KOH from 1 to 2.

$$2KOH(aq) + H_2S(aq) \rightarrow K_2S(aq) + H_2O(l)$$

| | |
|---|---|
| 2 K | 2 K |
| 2 O | 1 O |
| 4 H | 2 H |
| 1 S | 1 S |

Now, K and S are balanced, but oxygen and hydrogen are not. There are four hydrogen and two oxygen atoms on the left, but only two hydrogen and two oxygen atoms on the right. If we adjust the coefficient of water to 2, oxygen and hydrogen are the same on each side, and the equation is balanced.

$$2KOH(aq) + H_2S(aq) \rightarrow K_2S(aq) + 2H_2O(l)$$

| | |
|---|---|
| 2 K | 2 K |
| 2 O | 2 O |
| 4 H | 4 H |
| 1 S | 1 S |

b. Because $HNO_2$ is the most complex molecule, begin by adjusting the number of nitrogen atoms on both sides of the equation. There are two on the right, but only one on the left. Increase the coefficient of $HNO_2$ to 2. Hydrogen and oxygen are the same on each side, and the equation is balanced.

$$2HNO_2(aq) \rightarrow N_2O_3(g) + H_2O(aq)$$

| | |
|---|---|
| 2 H | 2 H |
| 2 N | 2 N |
| 4 O | 4 O |

c. Either NaOH or $H_2SO_4$ is a good place to begin balancing. Let's start by adjusting the number of sodium ions. Put a coefficient of 2 in front of NaOH.

$$2NaOH(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + H_2O(l)$$

| | |
|---|---|
| 2 Na | 2 Na |
| 6 O | 5 O |
| 4 H | 2 H |
| 1 S | 1 S |

There is one sulfur atom on each side, but the left side now has four hydrogen and six oxygen atoms while the right side has only five oxygen atoms and two hydrogen atoms. The right side can be adjusted by placing a coefficient of 2 in front of $H_2O$. The equation is now balanced.

$$2NaOH(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$$

| | |
|---|---|
| 2 Na | 2 Na |
| 6 O | 6 O |
| 4 H | 4 H |
| 1 S | 1 S |

d. Begin by adjusting the ammonium ion and the nitrate ion by putting a coefficient of 2 in front of $NH_4NO_3(aq)$. The equation is now balanced.

$$(NH_4)_2S(aq) + Pb(NO_3)_2(aq) \rightarrow PbS(s) + 2\ NH_4NO_3(aq)$$

| | |
|---|---|
| 4 N | 4 N |
| 8 H | 8 H |
| 1 S | 1 S |
| 1 Pb | 1 Pb |
| 6 O | 6 O |

e. The numbers of aluminum atoms and oxygen atoms on the left are less than on the right. Begin by increasing the coefficient of aluminum to 2. Aluminum is now balanced on both sides.

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

| | |
|---|---|
| 2 Al | 2 Al |
| 2 O | 3 O |

Aluminum is balanced, but oxygen is not. There are three oxygen atoms on the right and two on the left. We cannot use a coefficient on the left to produce three oxygen atoms so that the left and right balance. But we can put a coefficient of 2 in front of $Al_2O_3$ to make six oxygen atoms. A coefficient of 3 on the left adjusts the oxygen atoms on the left to six.

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

| | |
|---|---|
| 2 Al | 4 Al |
| 6 O | 6 O |

There are now four aluminum atoms on the right and two on the left, so increase the coefficient of aluminum on the left to 4. The equation is now balanced.

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

| | |
|---|---|
| 4 Al | 4 Al |
| 6 O | 6 O |

6.

a. $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$

b. $2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(g)$

c. $2Fe_2O_3(s) + 3C(s) \rightarrow 4Fe(s) + 3CO_2(g)$

d. $TiCl_4(l) + 2H_2O(l) \rightarrow TiO_2(s) + 4HCl(aq)$

7.

a. $2KI(aq) + Br_2(l) \rightarrow 2KBr(aq) + I_2(s)$

b. $2PbO_2(s) \rightarrow 2PbO(s) + O_2(g)$

c. $2Fe(OH)_3(s) + 3H_2SO_4(aq) \rightarrow Fe_2(SO_4)_3(s) + 6H_2O(l)$

d. $2K_3PO_4(aq) + 3BaCl_2(aq) \rightarrow 6KCl(aq) + Ba_3(PO_4)_2(s)$