Writing, Balancing and Predicting Products of Chemical Reactions.

A chemical equation is a concise shorthand expression which represents the relative amount of reactants and products involved in a chemical reaction.

$CO_2 + H_2O \rightarrow H_2CO_3$

reactants | product

The first step in writing a chemical equation is the word equation. It is composed of the names of the materials that enter into chemical reaction, the reactants, and the names of the materials that result from the reaction, the products. The second step in writing a chemical equation is a skeleton equation. This equation includes the chemical formulas and symbols for all the reactants and products. The third step is a balanced equation. This equation is similar to a skeleton equation, but it also includes coefficients placed directly in front of the chemical formulas and symbols. The coefficients of a balanced equation indicate the number of units of each substance involved. Hydrogen burns in oxygen to form water. The reactants are hydrogen and oxygen. The product is water. The word equation for this reaction is

hydrogen + oxygen → water

It is read, "hydrogen plus oxygen yield water." Since hydrogen and oxygen are diatomic gases, the H_2 and O_2 represent one molecule of hydrogen and one molecule of oxygen. The compound, water, is represented by the formula H_2O. The skeleton equation is
$H_2 + 0_2 \rightarrow H_2O$

The Balanced Equation

The skeleton equation indicates that two hydrogen atoms react with two oxygen atoms on the reactant side of the equation. On the product side, two hydrogen atoms are bonded to one oxygen atom. The equation is deficient by one oxygen atom on the product side. Balance the equation by putting coefficients directly in front of any of the reactants or products. A coefficient should be a whole number. *Never change the subscripts.* Changing the subscript changes the chemical formula of the compound. Place a 2 in front of the H_2O so that there are two oxygen atoms on each side of the equation.

$H_2 + O_2 \rightarrow 2H_2O$

The 2 placed in front of the H_2O changes the balance of the hydrogen atoms. Correct this imbalance by placing another 2 in front of the H_2. The equation is now balanced.

$2H_2 + 0_2 \rightarrow 2H_2O$

Symbols are used in an equation to indicate the physical state of each substance. The symbols used (placed in parenthesis) are (g) for gas, (1) for liquid, (c) for solid, and (aq) for aqueous (water) solution.

$2H_2(g) + O_2(g) \rightarrow 2H_2O(1)$

What can we infer from a balanced equation? An equation indicates:

(1) two parts of hydrogen react with one part of oxygen to yield two parts of water.
(2) two molecules of hydrogen react with one molecule of oxygen to give two molecules of water
(3) a quantitative relationship between the reactants and products. This relationship is the basis for working all quantitative problems.

Steps in Writing a Balanced Equation

Step 1. In writing a chemical reaction, the reactants and the products are written down. If the products are not known, they can be predicted in many cases.

Step 2. The formulas of each substance must be correct. The diatomic gases are hydrogen, H_2, nitrogen, N_2, oxygen, O_2, fluorine, F_2; chlorine, Cl_2, bromine, Br_2; and iodine, I_2.

Step 3. The equation is then balanced. The balancing is done by putting a coefficient before compounds until the atoms of each element on one side of the equation equal the number of atoms of that element on the other side of the equation.

Example 1

Sodium reacts with water to produce a metallic hydroxide and hydrogen gas. Write a balanced equation for the reaction.

Solving Process:

Step 1. *Write the word equation:*

sodium + water → sodium hydroxide + hydrogen

Step 2. *Write a skeleton equation.*

Since hydrogen is a diatomic gas, its formula is H_2. The formula for water may be written as HOH if this makes it easier to balance the equation.

$Na + HOH \rightarrow NaOH + H_2$

Step 3. *Balance the equation*.

The metallic element sodium is balanced. One atom of sodium is on each side of the equation. There is one hydrogen atom on the reactant side (the H in OH has been accounted for) and 2 hydrogen atoms on the product side. Place a 2 in front of the HOH to balance the hydrogen atoms.

$Na + 2HOH \sim NaOH + H_2$

There are now 2OH on the left and 1 on the right. Place a 2 in front of the NaOH to give the same number of OH on each side.

$Na + 2HOH \rightarrow 2NaOH + H_2$

Put a 2 in front of the sodium metal. The balanced equation reads

$2Na(c) + 2HOH(l) \rightarrow 2NaOH(aq) + H_2(g)$

Check visually to see if the equation is balanced, or list all the atoms (the hydroxide can be listed as OH or can be separated into H and 0).

Example 2

Iron(III) oxide reacts with carbon monoxide to give iron and carbon dioxide. What is the balanced equation?

Solving Process:

Step 1. *Write the word equation.*

iron(lll) oxide + carbon monoxide → iron + carbon dioxide

Step 2. *Write the formulas and symbols of all reactants and products*.

$Fe_2O_3 + CO \rightarrow Fe + CO_2$

Step 3. *Balance the iron atoms*.

$Fe_2O_3 + CO \rightarrow 2Fe + CO2$

The carbon atoms are already balanced. Visual inspection indicates that a 2 in front of the CO, to balance the oxygen atoms changes the carbon atom balance. A 2 in front of carbon monoxide results in an odd number of oxygen atoms on the reactant side. This change will not work because any number placed in front of carbon dioxide will always give an even number of oxygen atoms on the product side. A 3 in front of CO will give an even number of oxygen atoms on the reactant side. A 3 as a coefficient for CO, will balance the oxygen atoms and the carbon atoms. The balanced equation is

$Fe_2O_3c) + 3CO(g) \rightarrow 2Fe(c) + 3CO_2(g)$

Check the equation.

Example 3

Calcium hydroxide reacts with phosphoric acid to yield calcium phosphate and water. Determine the balanced equation.

Solving Process:

Step 1.

calcium hydroxide + phosphoric acid → calcium phosphate + water

Step 2.

$Ca(OH)_2 + H_3PO_4, \rightarrow Ca_3(PO_4)_3 + HOH$

Step 3. Balance the calcium atoms by placing a 3 in front of the $Ca(OH)_2$.

$3Ca(OH)_2 + H_3PO_4 \rightarrow Ca_3(PO_4)_2 + HOH$

Since the phosphate and hydroxide ions are on both sides of the equation they can be balanced as units. Place a 2 in front of the phosphoric acid to balance the PO_4, group. Place a 6 in front of the HOH to balance the OH group.

$3Ca(OH)_2(c) + 2H_3PO_4(l) \rightarrow Ca_3(PO_4)_2(c) + 6HOH(l)$

Visual inspection shows that the hydrogen in $H_3PO_4$and HOH is balanced. The hydrogen in the OH ion was balanced in Step 3. Check the balanced equation.

We have used only the smallest whole number coefficients. In balancing equations, you may sometimes obtain multiples of the smallest coefficients. If so, reduce the coefficients to the smallest whole numbers

possible.

Prediction of Products

The products of a chemical reaction may often be predicted by applying known facts about common reaction types. While there are hundreds of different ”kinds” of chemical reactions, only four general types of reactions will be considered; single displacement, double displacement, decomposition, and synthesis. The following sections give examples of these general types.

Single Displacement

One metallic element displaces another metallic element in a compound, or a nonmetallic element displaces another nonmetallic element in a compound. A single displacement has the general form

element + compound → element + compound

$$A+BX \rightarrow AX+B$$
$$X+BY \rightarrow BX+Y$$

The following are some general types of single displacement reactions.

1. An active metal will displace the metallic ion in a compound of a less active metal.

$$Fe(c) + Cu(NO_3)_2(aq) \rightarrow Fe(NO_3)_2(aq) + Cu(c)$$
$$Pb(c) + 2AgC_2H_3O_2(aq) \rightarrow Pb(C_2H_3O_2)_2,(aq) + 2Ag(c)$$

2. Some active metals such as sodium and calcium will react with water to give a metallic hydroxide and hydrogen gas.

$$2Na(c) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$$
$$Ca(c) + 2H_2O(1) \rightarrow Ca(OH)_2(aq) + H_2(g)$$

3. Active metals such as zinc, iron, and aluminum will displace the hydrogen in acids to give a salt and hydrogen gas.

$$Zn(c) + 2HC1(aq) \rightarrow ZnCl_2(aq) + H_2(g)$$
$$Fe(c) + H_2SO_4(aq) \rightarrow FeSO_4(aq) + H_2(g)$$

4. Halogens (which are active nonmetals) will displace less active halogens.

$$Cl_2(g) + 2NaBr(aq) \rightarrow 2NaC1(aq) + Br_2(aq)$$
$$Br_2(g) + 2KI(aq) \rightarrow 2KBr(aq) + I_2(g)$$

Double Displacement

The positive and negative ions of two compounds are interchanged. The form of these reactions is easy to recognize,

compound + compound → compound + compound

$$AX + BY \rightarrow AY + BX$$

The following are some general types of double displacement rcactions.

1. A reaction between an acid and a base yields a salt and water. Such a reaction is a neutralization reaction.

$2KOH(aq) + H_2SO4(aq) \rightarrow K_2SO_4\ (aq) + H_2O(l)$
$Ca(OH)_2(aq) + 2HNO_3(aq) \rightarrow Ca(NO_3)_2(aq) + 2H_2O(1)$

2. Reaction of a salt with an acid forms a salt of the acid and a second acid which is volatile.

$2KNO_3(aq) + H_2SO_4(aq) \rightarrow K_2SO_4(aq) + 2HNO_3(g)$
$FeS(c) + 2HC1(aq) \rightarrow FeCI_2(aq) + H_2S(g)$
$2NaC1(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2HCl(g)$

2a. This same reaction of a salt with an acid or base may yield a compound which can be decomposed.

$CaCO_3(aq) + 2HC1(aq) \rightarrow CaCl_2(aq) + H_2CO_3(aq)$
$H_2CO_3(aq) \rightarrow CO_2(g) + H_2O(1)$
or
$CaCO_3(c) + 2HC1(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(1)$
$K_2SO_3(aq) + 2HNO_3(aq) \rightarrow 2KNO_3(aq) + SO_2(g) + H_2O(1)$
$NH_4C1(aq) + NaOH(aq) \rightarrow NaC1(aq) + NH_2(g) + H_2O(1)$

3. Reaction of some soluble salts produces an insoluble salt and a soluble salt.

$AgNO_3(aq) + NaC1(aq) \rightarrow AgC1(c) + NaNO_3(aq)$
$Na_2SO_4(aq) + Ba(NO_3)_2(aq) \rightarrow BaSO_4(c) + 2NaNO_3(aq)$
$CuSO4(aq) + Na_2S(aq) \rightarrow CuS(c) + Na_2SO_4(aq)$
$Ca(C_2H_3O_2)_2(aq) + (NH_4)_2CO_3(aq) \rightarrow CaCO_3(c) + 2NH_4C_2H_3O_2(aq)$

Decomposition

When energy in the form of heat, electricity, light, or mechanical shock is supplied, a compound may decompose to form simpler compounds and/or elements. The general form for this type of reaction is

compound → two or more substances

$AX \rightarrow A + X$

The following are some general types of decomposition reactions.

1. If some acids are heated, they decompose to form water and an acidic oxide.

$H_2SO_3(aq) \rightarrow SO_2(g) + H_2O(1)$
$H_2CO_3(aq)\ CO_2(g) + H_2O(1)$

2. When some metallic hydroxides are heated, they decompose to form a metallic oxide and water.

$Ca(OH)_2(c) \rightarrow CaO(c) + H_2O(g)$
$2Fe(OH)_3(c) \sim Fe_2O_3(c) + 3H_2O(g)$

3. Some metallic carbonates decompose to form a metallic oxide and carbon dioxide when heated.

$Li_2CO_3(c) \rightarrow Li_2O(c) + CO_2(g)$
$CaCO_3(c) \rightarrow CaO(c) + CO_2(g)$

4. Metallic chlorates decompose to form metallic chlorides and oxygen when heated.

$2KC10_3(c) \rightarrow 2KC1(c) + 30_2(g)$
$Ni(C10_3)_2(c) \rightarrow NiC1_2,(c) + 30_2(g)$

5. Most metallic oxides are stable, but a few decompose when heated.

$2HgO(c) \rightarrow 2Hg(1) + O_2,(g)$
$2Ag_2O(c) \rightarrow 4Ag(c) + O_2(g)$

6. Some compounds cannot be decomposed by heat, but can be decomposed into their elements by electricity.

$2H_2O(1) \rightarrow 2H_2(g) + O_2(g)$
$2NaC1(1) \rightarrow 2Na(1) + Cl_2,(g)$
$MgCl_2(1) \rightarrow Mg(1) + Cl_2(g)$

Synthesis

In a synthesis reaction two or more simple substances (compounds and/or elements) are combined to form one new and more complex substance. Here the general form is

Element + element → compound
or
compound + compound → compound

$A + X \rightarrow AX$

The following are some general types of synthesis reactions.

1. Combination of elements.

$Fe(c) + S(1) \rightarrow FeS(c)$
$2Na(c) + Cl_2(g) \rightarrow 2NaCl(c)$

2. Combination of an acid anhydride with water to give an acid.

$SO_2(g) + H_2O(1) \rightarrow H_2SO_3(aq)$
$N_2O_3(g) + H_2O(1) \rightarrow 2HNO_2(aq)$
$CO_2(g) + H_2O(1) \rightarrow H_2CO_3(aq)$
$P_2O_5(c) + 3H_2O(l) \rightarrow 2H_3PO_4(aq)$

3. Combination of a basic anhydride or a metallic oxide with water to form a base.

$Na_2O(c) + H_2O(1) \rightarrow 2NaOH(aq)$
$CaO(c) + H_2O(1) \rightarrow Ca(OH)_2(aq)$
$BaO(c) + H_2O(1) \rightarrow Ba(OH)_2(aq)$

4. Combination of the metal of a basic oxide with the nonmetal of an acidic oxide to form a salt.

$CO_2(g) + Na_2O(c) \rightarrow Na_2CO_3(c)$
$P_2O_5(c) + 3BaO(c) \rightarrow Ba_3(PO_4)_2(c)$
$SO_2(g) + MgO(c) \rightarrow MgSO_3(c)$