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WRITING CHEMICAL EQUATIONS

SANTA FE COLLEGE Chemistry

Chemical equations are representations of reactions in terms of the formulas of the elements and/or compounds involved. Usually, the reactants (starting materials) appear on the left-hand side and the products appear on the right-hand side. An arrow, in between and always pointing from the reactants to the products, may be considered as an abbreviation for "yields."

Chemical equations report the results of experimentation and therefore great care must be taken so that the equation is in accord with the results of the experiment. A great deal of information is provided by the chemical equation; the exact nature of all reactants and products as well as the overall stoichiometry (ratio by which the species react) of the reaction is provided in this form of chemical shorthand. For any particular reaction the stoichiometry will always be unique. In order for the information to be understood universally, certain rules and conventions must be followed.

The same reactants under different reaction conditions can produce different products (or a different ratio of products). When this happens, two separate equations must be written. For example, methane (natural gas) burns in air to yield water and either pure carbon monoxide, pure carbon dioxide, or a mixture of the two. The unique equations for the formation of CO and CO_2 are:

$$2\,CH_4 + 3\,O_2 \longrightarrow 4\,H_2O + 2\,CO\text{ , and}$$

$$CH_4 + 2\,O_2 \longrightarrow 2\,H_2O + CO_2.$$

However, if you attempted to write an equation which produced both CO and CO_2, you could write an infinite number of such equations, each with a different ratio of CO to CO_2. Such equations could also be obtained by combining the above two equations in different ratios. But, you would not want to do this because the equations would not be unique.

Therefore, the question we need to answer is: What does a chemical equation mean? One must first realize that chemical equations can be interpreted on different levels; the large scale (sometimes called macroscale) and the small scale (sometimes called the nanoscale or microscale).

Choosing the first equation as an example, it means:

> **IF methane reacts with oxygen to yield water and carbon monoxide, then for every two moles of methane that reacts, three moles of oxygen react with it, to yield four moles of water and two moles of carbon monoxide.**

Since the species in the given equation are molecular, "molecules" can be substituted for "moles" in this statement. This substitution would then yield the statement:

> **IF methane reacts with oxygen to yield water and carbon monoxide, then for every two molecules of methane that reacts, three molecules of oxygen react with it, to yield four molecules of water and two molecules of carbon monoxide.**

RULES AND CONVENTIONS FOR WRITING CHEMICAL EQUATIONS.

THE EQUATION MUST BE IN ACCORD WITH THE CHEMICAL FACTS.

The first step in writing a chemical equation is to ascertain all of the reactants and products of the reaction in question including their physical states. Knowing what phase the reactant/product is in will determine how to write the species appropriately. (Also, you would want as much quantitative information about the species as possible.) This entire process is referred to as "inventorying" the system. Then, the following conventions can be applied:

Ionic symbols are used whenever separated, individual ions are present.

Therefore, ionic symbols are used:

- when a solution (usually an aqueous solution) is formed from any ionic compound (A.K.A. salt) or strong acid/base.
- when an ionic solid is vaporized to produce gas phase ions.

Molecular or empirical formulas are used for all other situations.

Therefore, molecular/empirical formulas are used for:

- all solids, whether they are molecular or ionic. (An ionic solid does not have separated ions.)
- all gases (except ionic compounds that are vaporized to the individual ions).
- all pure liquids, even though they may be very slightly ionized.
  E.g., concentrated sulfuric acid as H_2SO_4 (l) and water as H_2O (l).
- any substances in solution where the principal species present is the molecular substance, itself.
  E.g., acetic acid in water (i.e., vinegar) as CH_3COOH (aq) or the shorthand, HOAc (aq).

Examples: Na^+ (aq) and Cl^- (aq) for an aqueous solution of sodium chloride, but "NaCl (s)" for sodium chloride solid (ionic); and H_3O^+ (aq) and Cl^- (aq) for an aqueous solution of hydrogen chloride, but HCl (g) for pure (molecular) hydrogen chloride. The use of notation like "(aq)" or "(s)" to denote the phase is optional when one is dealing with the "normal" state of the species. (E.g., it is reasonable to assume that NaCl means NaCl (s), rather than molten NaCl; that Na^+ means Na^+ (aq) rather than gaseous.)

THE EQUATION MUST BE BALANCED WITH RESPECT TO MASS (MATERIAL).

Since atoms of any specific element cannot be converted into atoms of another element (that is, atoms cannot be created or destroyed) in a chemical reaction, a balanced chemical equation must always include the same number of each kind of atom on both sides of the equation arrow. (Law of Conservation of Mass.)

THE EQUATION MUST BE BALANCED WITH RESPECT TO CHARGE.

In a chemical reaction the law of conservation of mass holds for electrons as well as all other forms of matter and thus there must be the same <u>net</u> <u>charge</u> on each side of the equation arrow. (Charges cannot be created or destroyed.)

THE EQUATION MUST CONTAIN ONLY CHEMICALLY PERTINENT SPECIES.

The purpose of a chemical equation is to indicate the <u>chemical changes</u> that occur when the reactants become products and, therefore, the equation should include <u>only</u> those species which are <u>altered</u> <u>chemically</u> in the course of the reaction.

At the present time your knowledge of chemical facts is limited. Therefore, you are not in a position to accurately assess just how each chemical species should be represented in the equation nor are you in a position to decide which species are chemically pertinent. As a consequence, you should concentrate on making sure your equations are balanced with respect to charge and mass, a purely mechanical process. **(As the semester progresses the burden of knowing chemical facts and which species are pertinent will progressively be shifted to you.)** The following are some helpful hints on how to go about the mechanical process of balancing chemical equations.

MECHANICS OF BALANCING

Balancing chemical equations is a mechanical process which is best illustrated by example. Suppose you are given the task of writing the equation for the reaction of barium azide, $Ba(N_3)_2$, aqueous hydronium ion (H_3O^+) and oxygen gas to form aqueous barium ion (Ba^{+2}), nitrogen gas and water. It is helpful, when first learning to balance equations to begin by writing a "ZERO" coefficient in front of all species. I.e.:

$$\underline{0}\ Ba(N_3)_2\,(s) + \underline{0}\ H_3O^+\,(aq) + \underline{0}\ O_2\,(g) \longrightarrow \underline{0}\ Ba^{+2}\,(aq) + \underline{0}\ N_2\,(s) + \underline{0}\ H_2O\,(\ell)$$

When completed the equation must be balanced with respect to mass (# of Ba atoms, # of H atoms, # of N atoms and # of O atoms) as well as charge. So make a check-list of what needs to be done.

$$\underline{0}\ Ba(N_3)_2\,(s) + \underline{0}\ H_3O^+\,(aq) + \underline{0}\ O_2\,(g) \longrightarrow \underline{0}\ Ba^{+2}\,(aq) + \underline{0}\ N_2\,(s) + \underline{0}\ H_2O\,(\ell)$$

Ba

H

N

O

Charge

Start by selecting a species (a type of atom or charge) which appears in **only one** formula on each side of the equation. In our example we may start with "Ba", "H", "N" or "charge" but **NOT** "O" as it appears in two formulas on the left side (i.e. in H_3O^+ and O_2). Because there are many ways to balance equations it doesn't matter which possibility we choose to start with each method will lead to the same unique equation. So let's choose (arbitrarily) "H" and begin to balance by placing the numeral "1" in front of the "H" containing species with the most numbers of "H" in it. In this instance we place the numeral "1" in front of the "H_3O^+".

$$\underline{0}\ Ba(N_3)_2\,(s) + \underline{1}\ H_3O^+\,(aq) + \underline{0}\ O_2\,(g) \longrightarrow \underline{0}\ Ba^{+2}\,(aq) + \underline{0}\ N_2\,(s) + \underline{0}\ H_2O\,(\ell)$$

Thus we have "3" hydrogen atoms on the left side and therefore we must make sure we have "3" atoms of hydrogen on the right. This requires that we place a coefficient of 3/2 in front of the "H_2O" on the right (because $\underline{3/2} \times 1$ "H_2" = 3 "H").

$$\underline{0}\ Ba(N_3)_2\,(s) + \underline{1}\ H_3O^+\,(aq) + \underline{0}\ O_2\,(g) \longrightarrow \underline{0}\ Ba^{+2}\,(aq) + \underline{0}\ N_2\,(s) + \underline{\mathbf{3/2}}\ H_2O\,(\ell)$$

This balances the "H" atoms **mathematically but not chemically**. It make no chemical sense to have "fractions" of water molecules: we must have integer numbers of waters (as well as all species). Therefore the entire equation must be multiplied by two to "clear the fraction". Then update the check list!

$$\underline{0}\ Ba(N_3)_2\,(s) + \underline{2}\ H_3O^+\,(aq) + \underline{0}\ O_2\,(g) \longrightarrow \underline{0}\ Ba^{+2}\,(aq) + \underline{0}\ N_2\,(s) + \underline{3}\ H_2O\,(\ell)$$

Ba

H ✔

N

O

Charge

Note that only the coefficients in front of H_2O and H_3O^+ are changed as : $0 \times 2 = 0$.

We **CANNOT** choose any other coefficients - we must **deduce** all of the other coefficients. In our example, we still do not know the number of "Ba" atoms or "N" atoms on either side. Therefore we must balance the number of "O" atoms **or** the charge next. Notice, when we assigned a coefficient of three to "H_2O" we set the total number of "O" atoms on the right side to three. Likewise, when we assigned a coefficient of two to H_3O^+ we set the total charge on the left side to "+2" (as the other species carry no charge any coefficients for these species will leave the total charge on the left side at "+2") Again, it doesn't matter which we choose to balance next, the charge or the number of "O" atoms so we will choose (arbitrarily) the charge. Therefore, to balance the charge we must make the total charge "+2" on the right side. This is accomplished only by changing the coefficient of "Ba^{+2}" to "1" (1 × "+2" = "+2") .

$$\underline{\ 0\ }\ Ba(N_3)_2\,(s) + \underline{\ 2\ }\ H_3O^+\,(aq) + \underline{\ 0\ }\ O_2\,(g) \longrightarrow \underline{\ 1\ }\ Ba^{+2}\,(aq) + \underline{\ 0\ }\ N_2\,(s) + \underline{\ 3\ }\ H_2O\,(\ell)$$

At this point we can "check-off" the "Charge" from our list.

Ba	
H	✔
N	
O	
Charge	✔

Again, we cannot "choose" any other coefficients so we must inspect the partially balanced equation to find one of the remaining items on or check list which has only one unknown value. For example, there are no final coefficients for $Ba(N_3)_2$ on the left side and for N_2 on the right side. Thus, there are TWO unknown values for N left in the equation and therefore we cannot balance N at this point. However, when the coefficient of "Ba^{+2}" was changed to "1" it set the total atoms of "Ba" on the right side at "1" and therefore we must set the number of "Ba" atoms on the left side at "1".

$$\underline{\ 1\ }\ Ba(N_3)_2\,(s) + \underline{\ 2\ }\ H_3O^+\,(aq) + \underline{\ 0\ }\ O_2\,(g) \longrightarrow \underline{\ 1\ }\ Ba^{+2}\,(aq) + \underline{\ 0\ }\ N_2\,(s) + \underline{\ 3\ }\ H_2O\,(\ell)$$

Inspection again shows us that now the number of "N" atoms on the left is set at "6" (1 × 3 × 2 = 6) and therefore the number of "N" atoms on the right must also be set at "6". This is done by changing the coefficient in front of "N_2" to "3" (because 3 × 2 = 6). Now, "Ba" and "N" are "checked-off" our list.

$$\underline{\ 1\ }\ Ba(N_3)_2\,(s) + \underline{\ 2\ }\ H_3O^+\,(aq) + \underline{\ 0\ }\ O_2\,(g) \longrightarrow \underline{\ 1\ }\ Ba^{+2}\,(aq) + \underline{\ 3\ }\ N_2\,(s) + \underline{\ 3\ }\ H_2O\,(\ell)$$

Ba	✔
H	✔
N	✔
O	
Charge	✔

Now, only the number of atoms of "O" remain to be fixed. This is more difficult because "O" appears in several species in the equation. It will require a little more arithmetic than the other species.

Inspection shows us that the total number of atoms of "O" on the right side is set already at "3" and therefore we must fix the total number of atoms of "O" on the left at "3". On the left side we already have 2 "O" atoms from "H_3O^+", thus we need one more "O" atom on the left side and it must come from "O_2" as the other coefficient are already set. Thus the coefficient of "O_2" must be 1/2 (because <u>1/2</u> × 1 "O_2" = 1 "O")

$$\underline{\ 1\ }\ Ba(N_3)_2\,(s) + \underline{\ 2\ }\ H_3O^+\,(aq) + \underline{\ 1/2\ }\ O_2\,(g) \longrightarrow \underline{\ 1\ }\ Ba^{+2}\,(aq) + \underline{\ 3\ }\ N_2\,(s) + \underline{\ 3\ }\ H_2O\,(\ell)$$

Once again the equation is balanced mathematically but not chemically so we must multiply the entire equation by two to obtain the final equation and complete our "check-list".

$$\underline{\ 2\ }\ Ba(N_3)_2\,(s) + \underline{\ 4\ }\ H_3O^+\,(aq) + \underline{\ 1\ }\ O_2\,(g) \longrightarrow \underline{\ 2\ }\ Ba^{+2}\,(aq) + \underline{\ 6\ }\ N_2\,(s) + \underline{\ 6\ }\ H_2O\,(\ell)$$

Ba	✔
H	✔
N	✔
O	✔
Charge	✔

Balancing Chemical Equations : Homework

1. Balance the following equations:

$$\_\_XXXX + \_\_ O_2 \longrightarrow \_\_ CO_2 + \_\_ H_2O$$

a) XXXX = C_3H_8 b) XXXX = C_8H_{18}

c) XXXX = C_2H_6O d) XXXX = $C_5H_{10}O_2$

2. Balance the following equations:

$$\_\_XXXX + \_\_ O_2 \longrightarrow \_\_ CO_2 + \_\_ H_2O + \_\_ N_2$$

a) XXXX = CH_3NO_2 b) XXXX = $C_2H_8N_2$

c) XXXX = $C_2H_5NO_2$ d) XXXX = $C_6H_5NO_2$

3. Balance the following equations:

$$\_\_XXXX + \_\_ O_2 + \_\_ OH^- \longrightarrow \_\_ CO_3^{-2} + \_\_ H_2O + \_\_ N_2$$

a) XXXX = $C_{12}H_8N_2$ b) XXXX = $C_{10}H_8N_2$

c) XXXX = $C_2H_5NO_2$ d) XXXX = CH_2N_2

4. Balance the following equations:

$$\_\_XXXX + \_\_ N_2O \longrightarrow \_\_ CO_2 + \_\_ H_2O + \_\_ N_2$$

a) XXXX = $C_{12}H_8N_2$ b) XXXX = $C_{10}H_8N_2$

c) XXXX = $C_2H_5NO_2$ d) XXXX = CH_2N_2

5. Balance the following equations:

$$\_\_XXXX + \_\_ N_2O + \_\_ OH^- \longrightarrow \_\_ CO_3^{-2} + \_\_ H_2O + \_\_ N_2$$

a) XXXX = CH_3NO_2 b) XXXX = $C_2H_8N_2$

c) XXXX = $C_2H_5NO_2$ d) XXXX = $C_6H_5NO_2$

Balancing Chemical Equations : Homework Answer Key

1. a) $\underline{1}\ C_3H_8 + \underline{5}\ O_2 \longrightarrow \underline{3}\ CO_2 + \underline{4}\ H_2O$

   b) $\underline{2}\ C_8H_{18} + \underline{25}\ O_2 \longrightarrow \underline{16}\ CO_2 + \underline{18}\ H_2O$

   c) $\underline{1}\ C_2H_6O + \underline{3}\ O_2 \longrightarrow \underline{2}\ CO_2 + \underline{3}\ H_2O$

   d) $\underline{2}\ C_5H_{10}O_2 + \underline{13}\ O_2 \longrightarrow \underline{10}\ CO_2 + \underline{10}\ H_2O$

2. a) $\underline{4}\ CH_3NO_2 + \underline{3}\ O_2 \longrightarrow \underline{4}\ CO_2 + \underline{6}\ H_2O + \underline{2}\ N_2$

   b) $\underline{1}\ C_2H_8N_2 + \underline{4}\ O_2 \longrightarrow \underline{2}\ CO_2 + \underline{4}\ H_2O + \underline{1}\ N_2$

   c) $\underline{4}\ C_2H_5NO_2 + \underline{9}\ O_2 \longrightarrow \underline{8}\ CO_2 + \underline{10}\ H_2O + \underline{2}\ N_2$

   d) $\underline{4}\ C_6H_5NO_2 + \underline{25}\ O_2 \longrightarrow \underline{24}\ CO_2 + \underline{10}\ H_2O + \underline{2}\ N_2$

3. a) $\underline{1}\ C_{12}H_8N_2 + \underline{14}\ O_2 + \underline{24}\ OH^- \longrightarrow \underline{12}\ CO_3^{-2} + \underline{16}\ H_2O + \underline{1}\ N_2$

   b) $\underline{1}\ C_{10}H_8N_2 + \underline{12}\ O_2 + \underline{20}\ OH^- \longrightarrow \underline{10}\ CO_3^{-2} + \underline{14}\ H_2O + \underline{1}\ N_2$

   c) $\underline{4}\ C_2H_5NO_2 + \underline{9}\ O_2 + \underline{16}\ OH^- \longrightarrow \underline{8}\ CO_3^{-2} + \underline{18}\ H_2O + \underline{2}\ N_2$

   d) $\underline{2}\ CH_2N_2 + \underline{3}\ O_2 + \underline{4}\ OH^- \longrightarrow \underline{2}\ CO_3^{-2} + \underline{4}\ H_2O + \underline{2}\ N_2$

4. a) $\underline{1}\ C_{12}H_8N_2 + \underline{28}\ N_2O \longrightarrow \underline{12}\ CO_2 + \underline{4}\ H_2O + \underline{29}\ N_2$

   b) $\underline{1}\ C_{10}H_8N_2 + \underline{24}\ N_2O \longrightarrow \underline{10}\ CO_2 + \underline{4}\ H_2O + \underline{25}\ N_2$

   c) $\underline{2}\ C_2H_5NO_2 + \underline{9}\ N_2O \longrightarrow \underline{4}\ CO_2 + \underline{5}\ H_2O + \underline{10}\ N_2$

   d) $\underline{1}\ CH_2N_2 + \underline{3}\ N_2O \longrightarrow \underline{1}\ CO_2 + \underline{1}\ H_2O + \underline{4}\ N_2$

5. a) $\underline{2}\ CH_3NO_2 + \underline{3}\ N_2O + \underline{4}\ OH^- \longrightarrow \underline{2}\ CO_3^{-2} + \underline{5}\ H_2O + \underline{4}\ N_2$

   b) $\underline{1}\ C_2H_8N_2 + \underline{8}\ N_2O + \underline{4}\ OH^- \longrightarrow \underline{2}\ CO_3^{-2} + \underline{6}\ H_2O + \underline{9}\ N_2$

   c) $\underline{2}\ C_2H_5NO_2 + \underline{9}\ N_2O + \underline{8}\ OH^- \longrightarrow \underline{4}\ CO_3^{-2} + \underline{9}\ H_2O + \underline{10}\ N_2$

   d) $\underline{2}\ C_6H_5NO_2 + \underline{25}\ N_2O + \underline{24}\ OH^- \longrightarrow \underline{12}\ CO_3^{-2} + \underline{17}\ H_2O + \underline{26}\ N_2$