CHEM1001 Worksheet 4: Moles and Stoichiometry

Model 1: Balancing Chemical Equations

Chemical equations specify how chemical reactions occur – the *reactants* used, the *products* formed and the amounts of each. A *balanced* equation has the same number of atoms of each element on both sides, because matter can neither be created nor destroyed. The reaction below is the combustion of propane:

$$C_3H_8(g) \ + \ O_2(g) \ \rightarrow \ CO_2(g) \ + \ H_2O(l)$$

Critical thinking questions

1. Which species are the reactants? Which are the products?

2. What information is provided by the numerical *subscripts*? (What is meant by the "2" in CO_2?)

3. How many C, H and O atoms are on the left of the arrow and how many C, H and O atoms are on the right of the arrow?

4. Is this equation balanced?

5. *Balance* the equation by adding numbers in front of the species so that the number of C, H and O atoms are the same on both sides of the arrow.

6. Why do we need to put numbers in front of the species, rather than just changing the subscript?

The numbers in front of each species are called ***stoichiometric coefficients***. If there is no explicit value, it means it is just 1. The coefficients provide information about the *ratio* of each of the species.

7. Using your balanced equation, how many molecules of CO_2 will be obtained from 2 molecules of C_3H_8?

8. How many molecules of O_2 are needed to obtain 16 molecules of H_2O?

Atoms are not the only thing that need to be balanced in a reaction. Charges do too. In the equation below, the atoms of each element are balanced, but the charges are not.

$$Cu^{2+}(aq) + \ Ag(s) \rightarrow \ Ag^{+}(aq) + \ Cu(s)$$

9. Balance the equation by adding the required stoichiometric coefficients.

10. How many atoms of Ag are required to make 3 atoms of Cu?

11. What do you think the "(g)", "(l)", "(s)" and "(aq)" symbols in the two equations above represent?

12. Complete the following equations.

(a) $Na_2CO_3(s) + HCl(aq) \rightarrow Na^+(aq) + Cl^-(aq) + CO_2(g) + H_2O(l)$

(b) $CH_3OH(l) + O_2 \rightarrow CO_2 + H_2O$

(c) $N_2 + H_2 \rightarrow NH_3(l)$

(d) $LiOH(s) + CO_2 \rightarrow Li_2CO_3(s) + H_2O(l)$

(e) $H_2SO_4(l) + H_2O(l) \rightarrow H_3O^+(aq) + SO_4^{2-}(aq)$

Model 2: Ionic reactions

When a soluble salt is placed in water, it separates into its ions. For example:

$NaCl(s) \rightarrow Na^+(aq) + Cl^-(aq)$
$Mg(NO_3)_2(s) \rightarrow Mg^{2+}(aq) + 2NO_3^-(aq)$

In the solution, there are no "NaCl" or "$Mg(NO_3)_2$" molecules in the solution: the ions are separated and water molecules surround each. Writing NaCl(aq) or $Mg(NO_3)_2(aq)$ is incorrect.

Critical thinking questions

1. Complete the ionic equations for the *dissolution* of the following soluble salts. (*Hint*: make sure you balance the equations and take special care when doing this for salts containing polyatomic ions.)

(a) $MgSO_4(s) \rightarrow$

(b) $Na_2SO_4(s) \rightarrow$

(c) $Mg(NO_3)_2(s) \rightarrow$

(d) $NaCH_3CO_2(s) \rightarrow$

From above, a solution of NaCl contains $Na^+(aq)$ and $Cl^-(aq)$ and a solution of $MgNO_3$ contains $Mg^{2+}(aq)$ and $NO_3^-(aq)$. If you mix a solution of each of these, nothing happens – we have the same present at the end:

$Na^+(aq) + Cl^-(aq) + Mg^{2+}(aq) + 2NO_3^-(aq) \rightarrow Na^+(aq) + Cl^-(aq) + Mg^{2+}(aq) + 2NO_3^-(aq)$

Ions which are present before and after can be crossed out of the equation: they are just "standing around watching" and are called *spectator* ions:

$\cancel{Na^+(aq)} + \cancel{Cl^-(aq)} + \cancel{Mg^{2+}(aq)} + \cancel{2NO_3^-(aq)} \rightarrow \cancel{Na^+(aq)} + \cancel{Cl^-(aq)} + \cancel{Mg^{2+}(aq)} + \cancel{2NO_3^-(aq)}$

Spectator ions should not be included as they give the impression that something is happening.

The reverse of dissolution is *precipitation* in which an solid forms from the ions in solution. The salt AgCl is insoluble: very little dissolves in solution. If $Ag^+(aq)$ and $Cl^-(aq)$ ions are mixed together than AgCl(s) will form:

$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$

2. You prepare a beaker containing a solution of magnesium chloride by dissolving $MgCl_2(s)$ in water. Write down the ionic equation for its dissolution.

3. You prepare a second beaker containing a solution of silver nitrate by dissolving $AgNO_3(s)$ in water. Write down the ionic equation for its dissolution.

4. You mix these two solutions together. What ions are present in this mixture?

5. When the solutions are mixed, a solid appears that, we tested, is silver chloride. By thinking about the ions that are present before and after mixing, write down the ionic equation for the reaction.

   (Remember that ions that are present before and after are spectators and should be crossed out. If you have included any spectator ions, remove them and write down the ionic equation.)

6. Write down the ionic equations for the precipitation reactions that occur when the following solutions are mixed.

   (a) A solution of Na_2SO_4 and a solution of $CaCl_2$. (*Hint*: calcium sulfate is insoluble).

   (b) A solution of NaOH and a solution of $MgSO_4$. (*Hint*: magnesium hydroxide is insoluble).

   (c) A solution of $Ca(OH)_2$ and a solution of $MgSO_4$ are mixed.

Model 3: Mole Concept

Atoms and molecules are *tiny*: there are as many water molecules in a drop of water as there are grains of sand on Earth. For this reason, counting the *number* of atoms or molecules is rather unwieldy. Chemists have invented a unit of counting called the *mole* (units *mol*). While it can seem complicated, it is similar to other units of counting which you are already familiar with. For example:

- 1 *pair* of objects = 2 objects
- 1 *dozen* objects = 12 objects
- 1 *mole* of objects = 6.022×10^{23} objects (this is called Avogadro's number).

Critical thinking questions

1. How many bread rolls are there in 2 dozen?

2. How many bread rolls are there in 2 moles?

3. How many bread rolls are there in ½ dozen?

4. How many bread rolls are there in 0.5 moles?

5. Derive a relationship between the number of items and the number of moles. (*Hint*: your relationship will involve Avogadro's number.)

Avogadro's number is not just a random large number. It is the number of atoms in exactly 12 g of pure carbon-12, so: 1 mol of carbon-12 has a mass of 12 g, and contains 6.022×10^{23} atoms. The *molar mass* (symbol *M*) is the mass of 1 mol of objects - it has units of g mol^{-1} (pronounced "grams per mole"). The relationship between the mass, the number of moles and the molar mass is:

$$\text{number of moles } (n) = \frac{\text{mass } (m)}{\text{molar mass } (M)} \quad \text{or} \quad n = \frac{m}{M}$$

6. What is the molar mass of carbon-12?

7. How many moles are there in 36 g of carbon-12?

8. The equation above gives a formula for calculating the number of moles (*n*) from the mass (*m*) and the molar mass (*M*). Write down a formula for calculating:

   (a) The mass (*m*) from the number of moles (*n*) and the molar mass (*M*)

   (b) The molar mass (*M*) from the number of moles (*n*) and the mass (*m*)

The molar mass of a compound is the sum of the mass numbers of the atoms in its formula:

- For H_2O, $M = [2 \times 1.008 \text{ (H)} + 16.00 \text{ (O)}]\text{ g mol}^{-1} = 18.02\text{ g mol}^{-1}$
- For $C_6H_{12}O$, $M = [6 \times 12.01 \text{ (C)} + 12 \times 1.008 \text{ (H)} + 1 \times 16.00 \text{ (O)}]\text{ g mol}^{-1} = 100.16\text{ g mol}^{1}$

9. Calculate the molar mass of the following:

   (a) calcium chloride

   (b) sulfur dioxide

10. Calculate the number of moles in each of the following:

    (a) 25 g of calcium chloride

    (b) 200.0 g of sulfur dioxide

    (c) 1 kg of iron

11. Calculate the mass of the following:

    (a) 15 mol of iron

    (b) 0.65 mol of sulfur dioxide