UNIT 3

AMOUNT OF SUBSTANCE

PART 3 – USING CHEMICAL EQUATIONS

$$6CO_2 + 6H_2O \xrightarrow[\text{nutrients}]{\text{sunlight}} C_6H_{12}O_6 + 6O_2$$

Organic compounds

Contents

Key words: reactant, product, stoichiometric coefficient, law of conservation of mass, laws of chemical combination

Units which must be completed before this unit can be attempted:
Unit 1 – Atomic Structure and the Periodic Table
Unit 2 – Particles, Structure and Bonding

1) Chemical Equations

(a) Introducing Chemical Equations

During chemical reactions, atoms and ions rearrange themselves and combine with other atoms and ions to form new substances.

The starting substances in a chemical reaction are called the **reactants**, and the new substances created in a chemical reaction are called **products**.

The chemical changes taking place in a chemical reaction are best shown in a chemical equation. Chemical equations always show:

- The chemical formulae of the reactants and products
- The relative number of moles of reactants reacting together, and the relative number of moles of products made; these relative numbers are written in front of their respective formulae and are known as stoichiometric coefficients

Chemical equations can also often show the state symbols of the reactants and products.

Eg $6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(aq) + 6O_2(g)$

In this reaction, carbon dioxide (CO_2) reacts with water (H_2O) to make glucose ($C_6H_{12}O_6$) and oxygen (O_2). Carbon dioxide and water are the reactants; glucose and water are the products.

The stoichiometric coefficients are 6, 6, 1 and 6. They show that per mole of glucose made, six moles of oxygen is made and six moles of both carbon dioxide and water are required. Stoichiometric coefficients do not show the actual amount of a substance which is reacting; they only show the ratio of the amounts of substance reacting.

If you know the number of moles of any one substance involved in the reaction, use can use the chemical equation to deduce the number of moles of all of the other substances involved:

Eg How many moles of water are needed to react with 0.03 moles of carbon dioxide?
Answer: 6 moles of water react with 6 moles of carbon dioxide (1:1 ratio), so 0.03 moles of water are needed to react with 0.03 moles of carbon dioxide.

Eg How many moles of glucose can you make from 0.03 moles of carbon dioxide?
Answer: 6 moles of carbon dioxide make 1 mole of glucose (6:1 ratio), so 0.03 moles of carbon dioxide will make 0.03/6 = 0.005 moles of glucose.

Eg How many moles of oxygen can you make from 0.03 moles of carbon dioxide?
Answer: 6 moles of carbon dioxide make 6 moles of oxygen (1:1 ratio), so 0.03 moles of carbon dioxide will make 0.03 moles of oxygen.

Test Your Progress: Topic 3 Part 3 Exercise 1

1. Using the equation $Mg + 2HCl \rightarrow MgCl_2 + H_2$:
   (a) How many moles of magnesium would be needed to react with 0.01 moles of hydrochloric acid?
   (b) How many moles of hydrogen could be produced from 0.01 moles of hydrochloric acid?
2. Using the equation $2 H_2S + 3O_2 \rightarrow 2SO_2 + 2H_2O$:
   (a) How many moles of oxygen are needed to react with 0.5 moles of hydrogen sulphide?
   (b) How many moles of sulphur dioxide can be made from 0.5 moles of hydrogen sulphide?
3. Using the equation $4K + O_2 \rightarrow 2K_2O$:
   (a) How many moles of oxygen are needed to react with 0.05 moles of potassium?
   (b) How many moles of potassium oxide can be made from 0.05 moles of potassium?

(b) Law of Conservation of Mass

During chemical reactions, particles are neither gained or lost; they are simply rearranged. If the reaction is taking place in a closed system, therefore, the total mass will remain constant over time, and the total mass of products will be the same as the total mass of reactants. This is known as the **Law of Conservation of Mass**.

It can be illustrated experimentally in several ways:

(i) During the precipitation of barium sulphate or silver nitrate
www.youtube.com/watch?v=mcnga-bbNXk

(ii) During the reaction between vinegar and baking powder
www.youtube.com/watch?v=FZwHH7Sm4hI

Together with the Law of Constant Composition and the Law of Multiple Proportions, these three laws are known as the **Laws of Chemical Combination**.

(c) Balancing Chemical Equations

According to the Law of Conservation of Mass, the total number of each type of atom in the reactants should be equal to the total number of each type of atom in the products. In this equation, for example:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

There are 6 carbon atoms, 12 hydrogen atoms and 18 oxygen atoms on both sides of the equation.

If you know the chemical formulae of all of the reactants and products in the equation, you can use the Law of Conservation of Mass to deduce what the stoichiometric coefficients must be. This is known as **balancing an equation.**

When balancing an equation, balance compounds first, then elements.

Eg: Write a balanced chemical equation to show how magnesium (Mg) reacts with oxygen (O_2) to make magnesium oxide (MgO)

Answer: Mg and O_2 are the reactants. There are at least 2 O atoms on the left-hand side, so there must be at least 2 O atoms on the right hand side.
So the stoichiometric coefficient in front of MgO must be at least 2.
This means there are at least 2 Mg atoms on the right-hand side, so there must also be at least 2 Mg atoms on the left-hand side.
So the stoichiometric coefficient in front of Mg must also be at least 2.
ie $2Mg + O \rightarrow 2MgO$; this equation is now balanced

Test Your Progress: Topic 3 Part 3 Exercise 2
The following chemical equations are not balanced. Balance them by adding the correct stoichiometric coefficients in front of the chemical formulae:

1. $N_2 + H_2 \rightarrow NH_3$
2. $Na + O_2 \rightarrow Na_2O$
3. $Al + Cl_2 \rightarrow AlCl_3$
4. $CH_4 + O_2 \rightarrow CO_2 + H_2O$
5. $HCl + O_2 \rightarrow Cl_2 + H_2O$

2) Calculating Reacting Quantities

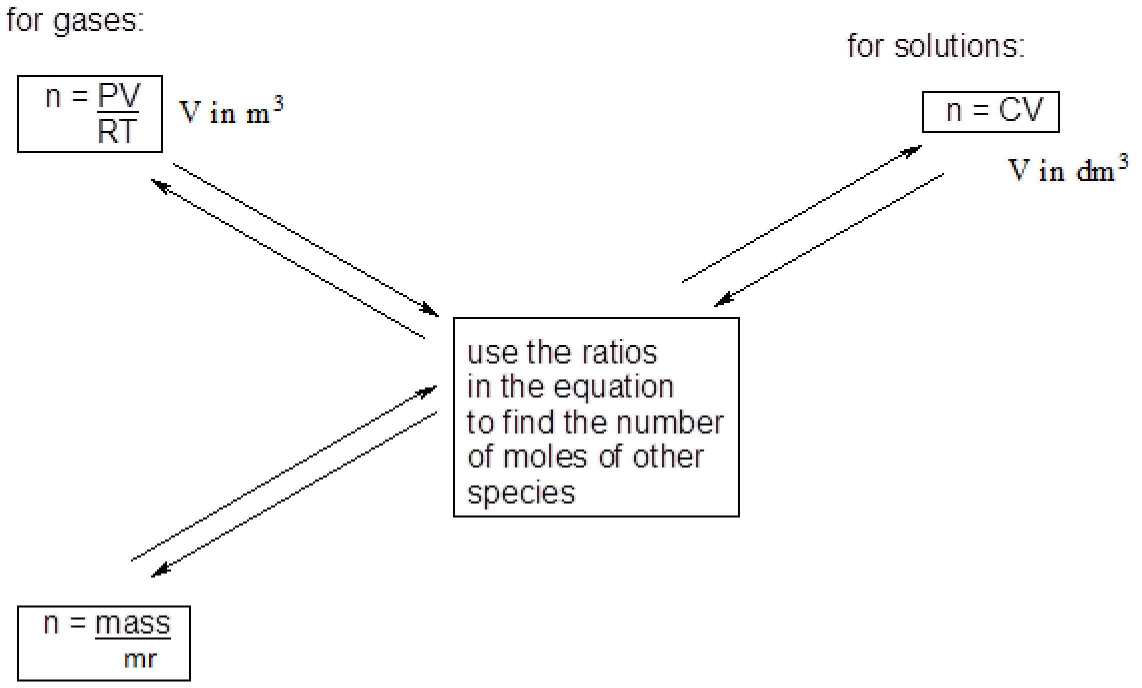
If you are given
- the mass of one substance in a chemical reaction, or
- the volume and concentration of one aqueous substance in a chemical reaction, or
- the volume, pressure and temperature of one gaseous substance in a chemical reaction,
  you can determine the number of moles of that one substance.

If you have the number of moles of one substance in the reaction, you can calculate the number of moles of everything else involved in the reaction. Using these moles, you can calculate any other quantity you need.

Eg — What volume (in dm^3) of hydrogen is produced at 298 K and 100 kPa when 192 g of magnesium is reacted with hydrochloric acid? $Mg + 2HCl \rightarrow MgCl_2 + H_2$

Answer: moles of Mg = 192/24 = 8
Mg and H react in a 1:1 ratio so moles of H_2 = 8
So volume of H_2 = 8 x 8.31 x 298/100000 = 0.198 m^3 = **198 dm^3**

The relationships between the important quantities are shown below:



Test Your Progress: Topic 3 Part 3 Exercise 2

1) What volume (in cm^3) of 0.5 $moldm^{-3}$ hydrochloric acid is required to react completely with 1.94 g of magnesium? $Mg + 2HCl \rightarrow MgCl_2 + H_2$
2) What volume (in dm^3) of oxygen at 298 K and 100 kPa is needed to react with 8.5 g of hydrogen sulphide (H_2S)? $2H_2S + 3O_2 \rightarrow 2SO_2 + 2H_2O$
3) What mass of potassium oxide is formed when 7.8 g of potassium is burned in excess oxygen? $4K + O_2 \rightarrow 2K_2O$
4) What volume of oxygen (in dm^3) at 298 K and 100 kPa is required to react with 10 g of ammonia? $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$
5) What mass of aluminium oxide is produced when 135 g of aluminium is burned in oxygen? $2Al + 3O_2 \rightarrow Al_2O_3$
6) What mass of iodine is produced when 2.4 dm^3 of chlorine gas reacts with excess potassium iodide at 298 K and 100 kPa? $Cl_2 + 2KI \rightarrow 2KCl + I_2$
7) What volume (in dm^3) of hydrogen is needed to react with 32 g of copper oxide at 200 ^oC and 100 kPa? $CuO + H_2 \rightarrow Cu + H_2O$
8) What volume of oxygen is formed at 398 K and 100 kPa when 735 g of potassium chlorate decomposes? $2KClO_3 \rightarrow 2KCl + 3O_2$
9) What volume of hydrogen is produced when 195 g of potassium is added to water at 298 K and 100 kPa? $2K + 2H_2O \rightarrow 2KOH + H_2$
10) What mass of calcium carbonate is required to produce 1.2 dm^3 of carbon dioxide at 398 K and 100 kPa? $CaCO_3 \rightarrow CaO + CO_2$
11) What mass of magnesium oxide is formed when magnesium reacts with 6 dm^3 of oxygen at 298 K and 100 kPa? $2Mg + O_2 \rightarrow 2MgO$
12) What volume of carbon dioxide (in dm^3) is produced when 5.6 g of butene (C_4H_8) is burnt at 298 K and 100 kPa? $C_4H_8 + 6O_2 \rightarrow 4CO_2 + 4H_2O$
13) The pollutant sulphur dioxide can be removed from the air by reaction with calcium carbonate in the presence of oxygen. What mass of calcium carbonate is needed to remove 480 dm^3 of sulphur dioxide at 298 K and 100 kPa? $2CaCO_3 + 2SO_2 + O_2 \rightarrow 2CaSO_4 + 2CO_2$
14) 25 cm^3 of a solution of sodium hydroxide reacts with 15 cm^3 of 0.1 $moldm^{-3}$ HCl. What is the molar concentration of the sodium hydroxide solution? $HCl + NaOH \rightarrow NaCl + H_2O$
15) Calculate the mass of H_2O required to react completely with 5.0 g of $SiCl_4$: $SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$
16) Calculate the mass of phosphorus required to make 200 g of phosphine, PH_3, by the reaction: $P_4(s) + 3NaOH(aq) + 3H_2O(l) \rightarrow 3NaH_2PO_2(aq) + PH_3(g)$
17) Lead (IV) oxide reacts with concentrated hydrochloric acid as follows: $PbO_2(s) + 4HCl(aq) \rightarrow PbCl_2(s) + Cl_2(g) + 2H_2O(l)$
    What mass of lead chloride would be obtained from 37.2g of PbO_2?
18) When copper (II) nitrate is heated, it decomposes according to the following equation: $2Cu(NO_3)_2(s) \rightarrow 2CuO(s) + 4NO_2(g) + O_2(g)$.
    If 20.0g of copper (II) nitrate is heated, what mass of copper (II) oxide would be produced?
19) 25 cm^3 of a solution of 0.1 $moldm^{-3}$ NaOH reacts with 50 cm^3 of a solution of hydrochloric acid (HCl). What is the molarity of the acid? $HCl + NaOH \rightarrow NaCl + H_2O$
20) 25.0 cm^3 of a 0.10 $moldm^{-3}$ solution of sodium hydroxide was titrated against a solution of hydrochloric acid of unknown concentration. 27.3 cm^3 of the acid was required. What was the concentration of the acid? $HCl + NaOH \rightarrow NaCl + H_2O$

Test Your Progress: Topic 3 Part 3 Exercise 3

1) 10 cm^3 of a solution of NaCl react with 15 cm^3 of a 0.02 $moldm^{-3}$ solution of $AgNO_3$. What is the concentration of the NaCl solution in gdm^{-3}? $NaCl + AgNO_3 + AgCl + Na\ NO_3$
2) 25 cm^3 of a 0.1 $moldm^{-3}$ solution of an acid H_xA reacts with 75 cm^3 of a 0.1 $moldm^{-3}$ solution of NaOH. What is the value of x? $H_xA + xNaOH \rightarrow + Na_xA + xH_2O$
3) A solution of hydrochloric acid (HCl) of volume 25.0 cm^3 was pipetted onto a piece of calcium carbonate. When all action had ceased, 1.30g of the marble had dissolved. Find the concentration of the acid. $CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O$
4) What volume of 0.1 $moldm^{-3}$ hydrochloric acid (HCl) would be required to dissolve 2.3 g of calcium carbonate? $CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$
5) 2.05 g of the carbonate of an unknown alkali metal (X_2CO_3) required 8.9 cm^3 of 2.0 $moldm^{-3}$ hydrochloric acid to completely dissolve it. What was the relative atomic mass of the metal and which metal was it? $X_2CO_3(s) + 2HCl(aq) \rightarrow 2XCl(aq) + CO_2(g) + H_2O(l)$
6) 10.0 g of calcium nitrate is heated at 100 kPa and a temperature of 300 ^oC, at which temperature it fully decomposes. Calculate
   a) the volume of nitrogen dioxide evolved
   b) the volume of oxygen evolved
   c) the total volume of gas evolved

   Equation: $2Ca(NO_3)_2(s) \rightarrow 2CaO(s) + 4NO_2(g) + O_2(g)$
7) Calculate the volume of oxygen produced at 298 K and 100 kPa by the decomposition of 30 cm^3 of 0.1 $moldm^{-3}$ hydrogen peroxide. $2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$
8) Lead (IV) oxide dissolves in concentrated hydrochloric acid according to the following equation:

   $$PbO_2(s) + 4HCl(aq) \rightarrow PbCl_2(s) + Cl_2(g) + 2H_2O(l)$$

   Starting with 37.2 g of lead (IV) oxide, calculate:
   a) the volume of 12 $moldm^{-3}$ HCl needed to completely dissolve it
   b) the mass of $PbCl_2$ produced
   c) the volume of chlorine produced at 298 K and 100 kPa
9) What mass of magnesium, and what volume of 2.0 $moldm^{-3}$ hydrochloric acid, will be required to produce 100 cm^3 of hydrogen gas at 298 K and 100 kPa? $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$
10) 0.52 g of sodium was added to 100 cm^3 of water. Calculate:
   a) The volume of hydrogen evolved at 298 K and 100 kPa
   b) The concentration of the sodium hydroxide solution produced, assuming the volume of water does not change.

   Equation: $2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$