FACTFILE: GCE CHEMISTRY

Rewarding Learning

1.1 FORMULAE, EQUATIONS AND AMOUNTS OF SUBSTANCE

Formulae, equations and amounts of substance

Learning Outcomes

Students should be able to:

1.1.1 write formulae of ionic compounds by predicting the ionic charge from the position of an element in the Periodic Table and by recalling molecular ions and their formulae;

1.1.2 write and balance equations for unfamiliar reactions given appropriate information;

1.1.3 write balanced equations (full and ionic) including state symbols, for all reactions studied;

1.1.4 define and demonstrate understanding of the terms Avogadro's constant, the mole and molar mass;

1.1.5 use Avogadro's constant in calculations;

1.1.6 calculate reacting masses of substances including examples in which some reactants are in excess;

1.1.7 demonstrate an understanding of the terms anhydrous, hydrated and water of crystallisation and be able to calculate the moles of water of crystallisation present from percentage composition, mass composition or experimental data.

Ionic Formulae

A chemical formula is a useful shorthand method for describing the atoms in a chemical. The chemical formula of an ionic compound tells you:

- which elements it contains;
- e.g. $FeSO_4$ contains iron, sulphur and oxygen;
- the ratio of metal ions to non-metal ions, e.g. NaCl contains one chloride ion for each sodium ion whereas $MgCl_2$ contains two chloride ions for every magnesium ion.

You can work out the formulae of **compounds containing metals** from the charges on the ions.

- Metal ions in **Group 1** always have charge **+**
- Metal ions in **Group 2** always have charge **2+**
- Metal ions in **Group 3** always have charge **3+**
- Non-metal ions of **Group 7** elements have charge **–**
- Non-metal ions of **Group 6** elements have charge **2–**
- Non-metal ions of **Group 5** elements have charge **3–**

In the compound, the number of positive and negative charges is equal so that the overall charge on the compound is zero.

A molecular ion is a species made up of two or more atoms covalently bonded with an overall charge. Some common examples include:

- sulfate, SO_4^{2-}
- sulfite, SO_3^{2-}
- thiosulfate, $S_2O_3^{2-}$
- hydrogensulfate, HSO_4^-
- hydrogencarbonate, HCO_3^-
- carbonate, CO_3^{2-}
- nitrate, NO_3^-
- nitrite, NO_2^-
- phosphate, PO_4^{3-}
- chlorate, ClO_3^-
- hypochlorite, ClO^-
- hydroxide, OH^-
- dichromate, $Cr_2O_7^{2-}$
- chromate, CrO_4^{2-}
- manganate(VII), MnO_4^-
- ammonium, NH_4^+

If more than one molecular ion is required in a formula brackets are used, for example, calcium hydrogencarbonate is $Ca(HCO_3)_2$.

Chemical Equations

Chemical equations do much more than tell us what reacts with what in a chemical reaction. They tell us how many of each species are needed and produced, so they also tell us what masses of the reactants are needed to produce a given mass of products. One of the most important things to understand in chemistry is that atoms are **rearranged** in chemical reactions. They are never produced from 'nowhere' and they do not simply 'disappear'. This means that in a chemical equation you must have the same number of each kind of atoms on the left-hand side of the equation as on the right. Consider the following reaction:

magnesium + oxygen → magnesium oxide

Magnesium is written as Mg (one atom just like carbon) and oxygen is, O_2 (one molecule). Magnesium oxide is composed of the magnesium ion, Mg^{2+} and the oxide ion, O^{2-}, and is therefore written as MgO.

$$\mathbf{Mg + O_2 \rightarrow MgO}$$

The magnesium balances, one atom on the left and one on the right, but the oxygen does not as there are two atoms on the left-hand side of the equation and only one on the right-hand side. **You cannot change the formulae of the reactants or products.** Each 'formula' of magnesium oxide has only one atom of oxygen but each molecule of oxygen has two atoms of oxygen, so you can make two formulae of magnesium oxide for each molecule of oxygen. So we get:

$$\mathbf{Mg + O_2 \rightarrow 2MgO}$$

Even now the equation does not balance, because we need two atoms of magnesium to make two formulae of MgO, and the final equation is:

$$\mathbf{2Mg + O_2 \rightarrow 2MgO}$$

This process can be summarised using the following rules:

1. Count the number of atoms on each side of the equation.
2. If the numbers of each type of atom is not the same then it has to be balanced.
3. Put big numbers in front of the formula which contain atoms that do not balance (never change the small numbers in formulae).
4. Continue until the number of each atom on each side are the same.

An ionic equation involves only those species which are undergoing change in the reaction. Those ions that are the same at the start and finish of the reaction are known as spectator ions. For example, the symbol and ionic equations for the reaction between magnesium and hydrochloric acid are:

Symbol: $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

Ionic: $Mg(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$

Numbers of particles

When a chemical reaction takes place the atoms are rearranged to make different species but no atoms can be made or destroyed. The mass of an individual atom is very small (approx 10^{-24} g) and it is much more convenient to measure atomic masses as **relative** masses.

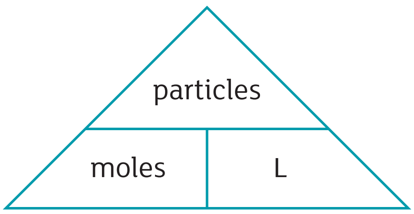
The relative atomic mass is the average (weighted mean) mass of an atom of an element relative to one-twelfth of the mass of an atom of carbon-12.

The relative atomic mass of carbon is 12. This corresponds to 6.02×10^{23} carbon atoms. This number is known as the Avogadro Constant (L) and is the number of atoms in 12.000 g of carbon-12.

The amount of a substance which contains this number of atoms is one mole of that substance.

When we need to know the number of particles of a substance, we usually count the number of moles. It is much easier than counting the number of particles. The number of particles can be calculated by multiplying the number of moles by Avogadro's number. The number of moles can be calculated by dividing the number of particles by Avogadro's number.

This is shown in the triangle:
moles x L gives number of particles;
moles = particles/L

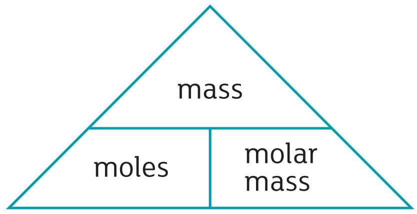


The mass of one mole of a substance

Molar mass is the mass of one mole of a substance. For example:

- 1 mole of C atoms has a mass of 12 g
- 1 mole of H atoms has a mass of 1 g
- 1 mole of H_2 molecules has a mass of 2 g

Mass, moles and molar mass can be interchanged - this is shown in the triangle below. Mass is moles x molar mass; moles = mass/molar mass and molar mass = mass/moles



Reacting mass calculations

A chemical equation such as:

$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$

is a kind of chemical balance sheet; it tells us that one mole of nitrogen reacts with three moles of hydrogen to yield two moles of ammonia. Such an equation is an essential starting point for many experiments and calculations; it tells us the proportions in which the substances react and the products are formed. A typical question involving mass-to-mass calculation is to ask for the mass of a product that could be obtained from a given mass of one of the reactants. After writing the chemical equation (which may be given), the calculation should be given in three steps:

Step 1: Calculate the number of moles of the reactant.

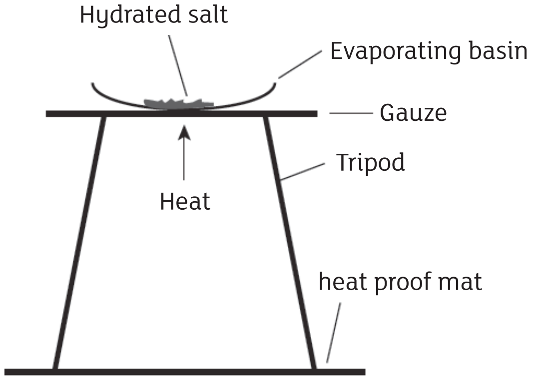
Step 2: Use the stoichiometry of the equation to calculate the number of moles of product (the stoichiometry of an equation is the ratio of the numbers of each reactant and product in the balanced equation).

Step 3: Convert the moles of product to mass.

Hydrated ionic compounds

Water of crystallisation is water which is chemically bonded within a crystal structure. The formula of a compound containing water of cyrstllisationincludes H_2O; $Na_2CO_3.xH_2O$ contains x number of molecules of water for every one formula of sodium carbonate. This is called **hydrated** sodium carbonate; if the sodium carbonate is heated in order to lose the water, we are left with anhydrous sodium carbonate, Na_2CO_3. Many hydrated salts gradually lose their water of crystallisation when left open to the atmosphere; heating the salt removes it more rapidly. By determining the mass of water lost the exact ratio of ionic compound to water and hence the formula of the hydrated compound can be determined.

An anhydrous salt is a salt which contains no water of crystallisation and a hydrated salt is a salt which contains water of crystallisation.



Revision Questions

1 Phosphoric acid is manufactured by the reaction of sulfuric acid with calcium phosphate according to the equation:

$3H_2SO_4 + Ca_3(PO_4)_2 \rightarrow 2H_3PO_4 + 3CaSO_4$

What mass of phosphoric acid would be obtained from reacting 60 kg of sulfuric acid with 60 kg of calcium phosphate?

A 19 kg
B 38 kg
C 40 kg
D 60 kg

2 You are required to plan an experiment to determine the degree of hydration in a sample sodium carbonate. If the sample of hydrated sodium carbonate is heated in a crucible to constant mass and appropriate masses measured, the value of *x* in the formula $Na_2CO_3.xH_2O$ can be found.

a) (i) Eplain the meaning of the term '**hydrated** sodium carbonate'.

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(ii) Draw a labelled diagram to show the apparatus which could be used to heat the hydrated sodium carbonate.

? Revision Questions

2 b) (i) What masses should be recorded before heating the hydrated sodium carbonate?

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(ii) The hydrated sodium carbonate is heated to remove all the water. What steps would you take to ensure that it had all been removed?

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(iii) After heating, state **one** safety precaution which should be followed before weighing.

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c) When 11.44 g of hydrated sodium carbonate was heated, 4.24 g of anhydrous sodium carbonate was formed.

(i) What is the mass of water lost?

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(ii) What is the number of moles of water lost?

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(iii) What is the number of moles of anhydrous sodium carbonate formed?

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(iv) Calculate the value of x in $Na_2CO_3.xH_2O$.

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3 When burned in a plentiful supply of oxygen, propane (C_3H_8) produces carbon dioxide and water.
$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

What is the number of molecules of carbon dioxide produced when 4.4 g of propane are burned?

A 6.02×10^{22}
B 1.81×10^{23}
C 6.02×10^{23}
D 1.81×10^{23}