CHEMISTRY 2.1

Internally assessed
4 credits

Carry out quantitative analysis

Quantitative chemistry is finding out:

- how much is present in a chemical substance, or
- how much is involved in a chemical reaction, for one or more chemicals.

Significant figures indicate the level of accuracy of the data and/or apparatus. In calculations, final answers typically include three significant figures, and no rounding should occur until the final answer.

Even small amounts of substances contain very large numbers of particles, e.g. a cup of water contains about 8.3×10^{24} water molecules. Although the number of particles handled in chemistry is very large, the masses of each of these particles are usually very small. The mass of a chlorine molecule is about 1.18×10^{-22} g. It would take about 10^{22} chlorine molecules to equal a mass of just 1 g. Since these masses are small, the unit **gram** (symbol **g**) is used.

The mole

When particularly large number of objects are needed, quantities are defined which suit these large numbers. In chemistry, the quantity chosen to describe the amount of a substance is the **mole**, abbreviated to **mol** when used as a unit. The amount of substance (in mol) is represented by the symbol n (thus $n(H_2O)$ means the amount of water in moles).

The mole is defined as 'the amount of substance which contains the same number of particles (atoms, ions or molecules) as there are atoms in exactly 12 g of carbon-12 (^{12}C or C-12)'.

Examples

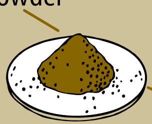
12 g of carbon is 1 mol of carbon.

The number of carbon atoms in 12 g of carbon is: 602 000 000 000 000 000 000 000, or 6.02×10^{23} atoms.

58.5 g of sodium chloride is 1 mol of sodium chloride.

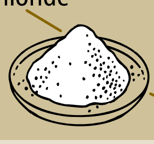
The number of sodium chloride ion pairs in 58.5 g is 6.02×10^{23}.

12 g of carbon powder



filter paper

58.5 g of sodium chloride



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Avogadro's number

A mole always contains 6.02×10^{23} particles. This is called **Avogadro's number**, N_A

$$N_A = 6.02 \times 10^{23}\ \text{mol}^{-1}$$

Avogadro's number is sometimes approximated to 6×10^{23} mol^{-1}

AS 91162

Activity 2A: Formulae of ionic compounds

Write the chemical formula of the following compounds:

1. sodium carbonate ______
2. zinc iodide ______
3. copper hydroxide ______
4. lead nitrate ______
5. ammonium sulfate ______
6. iron(II) chloride ______
7. aluminium hydroxide ______
8. iron(III) sulfate ______
9. barium sulfate ______
10. magnesium nitrate ______

Solubility rules

These solubility rules describe which ionic compounds are soluble in water and which are insoluble in water.

Compound	Solubility	Exceptions
nitrate	Soluble	None
chloride	Soluble	silver chloride, $AgCl$; lead chloride, $PbCl_2$
iodide	Soluble	silver iodide, AgI; lead iodide, PbI_2
sulfate	Soluble	lead sulfate, $PbSO_4$; barium sulfate, $BaSO_4$
hydroxide	Insoluble	*barium hydroxide, $Ba(OH)_2$; sodium hydroxide, $NaOH$
carbonate	Insoluble	sodium carbonate, Na_2CO_3; ammonium carbonate, $(NH_4)_2CO_3$

*barium hydroxide is sparingly soluble.

Activity 2B: Solubility of ionic compounds

Using the table of solubility rules, identify the following compounds (listed by name or by formula) as soluble or insoluble.

1. lead nitrate ______
2. $PbCO_3$ ______
3. AgI ______
4. magnesium chloride ______
5. barium sulfate ______
6. $Al(OH)_3$ ______
7. $CuSO_4$ ______
8. iron(II) sulfate ______

Precipitate formation

When two soluble ionic compounds are mixed, there are four ions in solution. If one of the positive ions and one of the negative ions can combine to form an insoluble compound, then a **precipitate** will occur.

Example

Sodium carbonate, Na_2CO_3, solution added to copper sulfate, $CuSO_4$, solution results in Na^+ and CO_3^{2-}, Cu^{2+} and SO_4^{2-}, ions being present.

CHEMISTRY 2.3

Internally assessed
3 credits

Demonstrate understanding of the chemistry used in the development of a current technology

AS 91163

Introduction

This achievement standard requires the student to present a report on the 'Chemistry used in the development of a current technology', using appropriate chemistry vocabulary, symbols and conventions (including names, formulae and equations).

Before beginning this assessment, students will need to have had prior teaching and learning (at NCEA Level 2; Level 7 of the curriculum) of the chemistry relevant to the chosen topic.

Students need to *gather information* then *process and interpret* the information about the chosen technology and its related chemistry in order write the report.

You should be able to communicate your understanding by:

- giving an account of the *chemistry* related to the development of the technology you choose
- making and explaining links between the chemistry and the development of the technology
- evaluating how the chemistry has influenced the development of the technology.

Useful definitions

Chemistry – is the science that involves the study of matter. It covers the physical and chemical properties of different substances, such as how and why substances behave and react in the way they do.

Chemistry plays a major role in the creation and manufacture of new materials that we use in our everyday lives.

Chemistry involves three levels of understanding and/or representation:

- the observable (*macroscopic*) properties of substances – i.e. colour, state, smell, etc.
- the sub-microscopic (*molecular level*) properties of substances – i.e. the behaviour of atoms, ions, molecules, etc.
- the symbolic representation of substances/particles – i.e. use of chemical symbols, formulae and equations.

2. Calculate the heat energy released when 10 g NaOH is dissolved, given:

$$NaOH(s) \longrightarrow Na^+(aq) + OH^-(aq), \quad \Delta_r H = -20.2 \text{ kJ mol}^{-1}$$

Amount of NaOH: $n = \frac{m}{M}$

$= \frac{10 \text{ g}}{40 \text{ g mol}^{-1}}$ [substituting $M(NaOH) = 40 \text{ g mol}^{-1}$]

$= 0.25$ mol

1 mol of NaOH releases 20.2 kJ of heat energy,

$\therefore$ 0.25 mol of NaOH releases $0.25 \times 20.2 = 5.05$ kJ

The dependence of $\Delta_r H$ on state

Compare the two following thermochemical equations:

$$H_2(g) + \frac{1}{2}O_2(g) \longrightarrow 2H_2O(g) \qquad \Delta_r H = -242 \text{ kJ mol}^{-1} \qquad \textit{and}$$

$$H_2(g) + \frac{1}{2}O_2(g) \longrightarrow H_2O(\ell) \qquad \Delta_r H = -285 \text{ kJ mol}^{-1}$$

Both equations show *one mole of water forming* from hydrogen and oxygen but the $\Delta_r H$ values are different.

- The first equation shows water in gaseous form (g) as a product.
- The second equation shows liquid water (ℓ) as a product.
- The difference in $\Delta_r H$ values is 43 kJ.
- The amount of heat energy required to change one mole of liquid water to one mole of water vapour (the latent heat of vaporisation) is 43 kJ:

$$H_2O(\ell) \longrightarrow H_2O(g) \qquad \Delta_r H = 43 \text{ kJ mol}^{-1}$$

The value of $\Delta_r H$ depends on the *state* of each substance as well as the *amount* of each substance in the equation. It is important to use the *correct state symbols* in thermochemical equations.

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Activity 4H: Calculating energy changes

1. For the reaction $C_2H_5OH(\ell) + 3O_2(g) \longrightarrow 2CO_2(g) + 3H_2O(\ell)$, $\Delta_r H = -1\ 370 \text{ kJ mol}^{-1}$:
   a. calculate the heat energy released when 3 mol of ethanol reacts

   b. calculate the heat energy released when 1 mol of carbon dioxide forms

   c. calculate the heat energy released when 5.25 g ethanol, C_2H_5OH, reacts

   d. calculate the mass, in grams, of ethanol, C_2H_5OH, that must react to produce 2 500 kJ of heat energy.

c. 2,2,3-trimethylbutane

3. Draw and name the structural isomers of:

a. C_4H_{10}

b. C_5H_{12}

4. Explain the term *structural isomerism* and use an example in your explanation.

____

____

____

____

5. Complete the following sentences.

Alkanes undergo ____________ reactions with ____________ forming alkyl halides and hydrogen halides. The reactions are slow, and need the presence of ____________ or ____________.

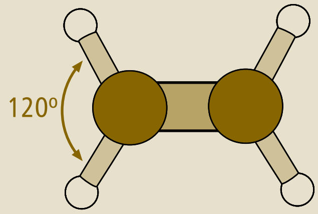
When ethane reacts with chlorine, the products are ____________ and ____________.

6. Complete the following substitution reaction:

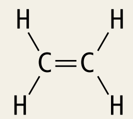
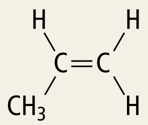
$CH_4 + I_2 \xrightarrow{\quad\_\_\ \_\_\quad}$ ____________ + ____________

Alkenes

In alkenes, two carbon atoms are joined by a double bond. Each of these two carbons atoms is bonded to two other atoms. All six atoms lie in a plane, with angles of 120° between the bonds.



The first two alkenes are ethene and propene.

Name	Molecular formula	Structural formula
ethene	C_2H_4	
propene	C_3H_6	

Ethene ripens fruit

Example

aminomethane and hydrochloric acid form the salt methyl ammonium chloride

$$CH_3NH_2(aq) + HCl(aq) \longrightarrow \underset{\text{methylammonium chloride}}{CH_3NH_3^+Cl^-(aq)}$$

Seawater is about 3% salt by weight, but the levels of dissolved minerals inside fish cells is $< 1\%$. To maintain fluid balance, fish cells contain trimethylamine oxide (TMAO). TMAO breaks down to form the fishy smell of trimethylamine, TMA. Adding acid (e.g. vinegar or lemon juice) to fish turns TMA into a non-smelling alkyl ammonium salt.

Activity 5I: Amines

1. Describe a simple test to confirm that a colourless organic liquid was an amine.

2. Give the IUPAC (systematic) name for each of the following:
   a. $CH_3CH_2CH_2CH_2CH_2CH_2NH_2$
   b. $CH_3CH_2CH_2NH_2$
3. Write the structural formula for 1-amino-3-methylbutane

4. Write the condensed structural formula for the alkylammonium ion formed when 1-aminopropane dissolves in water. Comment on the pH of the solution.

5. Write a balanced chemical equation for the reaction of 1-aminoethane with hydrochloric acid, and name the salt that is formed.

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The reactions of acids and bases in aqueous solutions involve the transfer of hydrogen ions, H^+ (hydrogen ions are protons).

- **Acids** are substances that *donate* protons.
- **Bases** are substances that *accept* protons.
- An **acid-base reaction** is one in which a proton is *transferred* from an acid to a base.

Hydrogen ions do not exist on their own in water but are always attached to water molecules and exist as **hydronium ions, H_3O^+**(aq). Hydronium ions are sometimes written as aqueous hydrogen ions, $H^+(aq)$.

Acids

Molecules such as hydrochloric acid, HCl, sulfuric acid, H_2SO_4, nitric acid, HNO_3, and ethanoic acid, CH_3COOH, act as acids by donating protons. The protons are transferred to water molecules to form hydronium ions, $H_3O^+(aq)$. The resulting aqueous solutions are **acidic solutions** because of the $H_3O^+(aq)$ ions that have been added.

Example

Hydrochloric acid

If hydrogen chloride gas, HCl(g), is dissolved in water, the reaction occurring is:

$$\overset{\text{acid}}{HCl(g)} + \overset{\text{base}}{H_2O(\ell)} \longrightarrow Cl^-(aq) + H_3O^+(aq)$$

proton transfer

HCl acts as an acid because it *donates* a proton. Water acts as a base because it accepts a proton (from the HCl molecule). The proton has been *transferred* from the HCl to the H_2O.

The resultant solution, called hydrochloric acid, is acidic because of the $H_3O^+(aq)$ ions present. The solution also contains chloride ions, $Cl^-(aq)$, and water molecules which did not accept protons.

The transfer of hydrogen ions can also be described as **ionisation** (since ions have formed) or **dissociation** (since the HCl molecule has, in effect, dissociated or been 'split up').

An ionisation or dissociation process (like the reaction in the previous Example), is sometimes written as:

$$HCl(g) \xrightarrow{H_2O} H^+(aq) + Cl^-(aq)$$

Strong and weak acids

Acids in which all the molecules completely dissociate in water are known as **strong acids**. Common strong acids are HCl, HNO_3 and H_2SO_4.

Example

Hydrochloric acid is a strong acid because all the molecules completely dissociate in water:

$$HCl(aq) + H_2O(\ell) \longrightarrow H_3O^+(aq) + Cl^-(aq)$$

Example

Redox reactions

All redox reactions involve the transfer of electrons.

	Redox reaction	Oxidation	Reduction
1.	Magnesium burning in oxygen to produce magnesium oxide: $2Mg + O_2 \longrightarrow 2MgO$	A magnesium atom has lost two electrons to become a magnesium ion: $Mg \longrightarrow Mg^{2+} + 2e^-$	An oxygen atom, in a molecule, has gained two electrons to become a negative ion: $O_2 + 4e^- \longrightarrow 2O^{2-}$
2.	Iron(II) ions, in solution, are oxidised to iron(III) ions in solution: $2Fe^{2+} + Cl_2 \longrightarrow 2Fe^{3+} + 2Cl^-$	An iron(II) ion has lost one electron to become an iron(III) ion: $Fe^{2+} \longrightarrow Fe^{3+} + e^-$	A chlorine atom, in a molecule, has gained one electron to become a chloride ion: $Cl_2 + 2e^- \longrightarrow 2Cl^-$
3.	Copper(II) ions in solution are reduced by magnesium atoms to produce copper atoms and magnesium ions: $Mg + Cu^{2+} \longrightarrow Mg^{2+} + Cu$	A magnesium atom has lost two electrons to become a magnesium ion: $Mg \longrightarrow Mg^{2+} + 2e^-$	A copper(II) ion has gained two electrons to become a copper atom: $Cu^{2+} + 2e^- \longrightarrow Cu$

Activity 7A: Oxidation-reduction reactions

Complete the following accounts of oxidation-reduction processes by supplying the missing words and formulae, using the following words:

addition complementary compound electron loses molecule oxidation reduction removed

1. Oxidation in its simplest form is the _________ of oxygen to an element or _________.

   The complement of oxidation is __________. No reaction can occur that involves the __________ process without the __________ process occurring.

2. Complete the account that follows for the following reaction:

$$2Fe^{3+} + 2I^- \longrightarrow 2Fe^{2+} + I_2$$

   The conversion of iron(III) ions to iron(II) ions is an example of __________ because an _________ has been gained by an iron(III) ion to produce an iron(II) ion.

   The ______________ process requires an electron to be ________.

   When an iodide ion _____ an electron, it becomes an iodine atom; two iodine atoms then combine to form an iodine _________.

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c. Acidified hydrogen peroxide solution converts a **colourless solution** to an orange solution.

d. A colourless solution of potassium iodide converts an **orange-red brown solution** to a black solid (and a very light green solution).

3. Explain the following observations, writing half-equations and an overall equation where appropriate.
   a. A pale-green gas passed over moist starch-iodide paper produces a blue-black stain on the paper.

   b. A gas, which appears in the air as white fumes, with a choking smell, is passed over acidified potassium permanganate paper and the paper is decolourised.

Activity 7E: Test yourself

The following questions are intended to reinforce the content of Achievement Standard 91167.

Note: Each set of questions below is related to one of the ***Activities 7A*** to ***7D***.

Question One: Oxidation-reduction reactions (Activity 7A)

1. Identify which of the following reactions are oxidation-reduction (redox) processes. Explain your decisions in terms of change in oxidation numbers.
   a. Iron rusting in damp air.

   b. $2Ca(s) + O_2(g) \longrightarrow 2CaO(s)$

AS 91167

ANSWERS

Achievement Standard 91161 (Chemistry 2.1)

Activity 1A: Molar mass (page 3)

1. $M(N_2) = 14.0 \times 2 = 28.0$ g mol^{-1}
2. $M(S_8) = 32.0 \times 8 = 256$ g mol^{-1}
3. $M(NaOH) = 23.0 + 16.0 + 1.00 = 40.0$ g mol^{-1}
4. $M(H_3PO_4) = 1.0 \times 3 + 31.0 + 16.0 \times 4 = 98.0$ g mol^{-1}
5. $M(C_6H_{12}O_6) = 12.0 \times 6 + 1.0 \times 12 + 16.0 \times 6 = 180$ g mol^{-1}
6. $M(C_2H_5OH) = 2 \times 12.0 + 6 \times 1.00 + 16.0 = 46$ g mol^{-1}
7. $M(MgCl_2) = 24.3 + 35.5 \times 2 = 95.3$ g mol^{-1}
8. $M(Mg(OH)_2) = 24.3 + 2 \times 16.0 + 2 \times 1.00 = 58.3$ g mol^{-1}
9. $M(Fe_2(SO_4)_3) = 55.9 \times 2 + 3 \times (32.0 + 16.0 \times 4) = 111.8 + 288.0$ $= 400$ g mol^{-1}
10. $M(CuSO_4.5H_2O) = 63.5 + 32.0 + 4 \times 16.0 + 5 \times 18.0$ $= 250$ g mol^{-1}

Activity 1B: Mole calculations (page 4)

1. a. i. $m(CO_2) = 1.00 \times 44.0 = 44.0$ g
   ii. $m(CO_2) = 1.25 \times 44.0 = 55.0$ g
   iii. $m(CO_2) = 30.0 \times 44.0 = 1\,320$ g
   b. $m(Al_2O_3) = 10.7 \times 102 = 1\,090$ g
   c. $m(SiO_2) = 0.875 \times 60.1 = 52.6$ g
2. a. $n(CaO) = \frac{154}{56.1} = 2.75$ mol b. $n(KCl) = \frac{8.65}{74.6} = 0.116$ mol
   c. $n(CaCO_3) = \frac{4.86}{100} = 0.0486$ mol
   d. $n(NH_4Cl) = \frac{2.39}{53.5} = 0.0447$ mol
   e. $n(CuSO_4.5H_2O) = \frac{5.44}{250} = 0.0218$ mol
3. a. $n(Cl^-) = 0.300$ mol b. $n(Cl^-) = 0.500$ mol
   c. $n(NaCl) = \frac{4.36}{58.5} = 0.0745$ mol, $n(Cl^-) = 0.0745$ mol
   d. $n(MgCl_2) = \frac{140}{95.3} = 1.47$ mol, $n(Cl^-) = 2 \times 1.47 = 2.94$ mol
   e. $n(FeCl_3) = \frac{0.372}{162} = 0.00230$ mol, $n(Cl^-) = 3 \times 0.00230$ $= 0.00690$ mol
4. a. $M(X) = \frac{33.5}{1.38} = 24.3$ g mol^{-1}
   b. $M(Y_4) = \frac{50.6}{0.408} = 124$ g mol^{-1}, $M(X) = \frac{124}{4} = 31.0$ g mol^{-1}

Activity 1C: Reacting masses (page 7)

1. $n(CuO) = \frac{1.27}{79.6} = 0.0160$ mol, $n(CuO) : n(Cu) = 1 : 1$
   $n(Cu) = 0.0160$ mol, $m(Cu) = 0.0160 \times 63.6 = 1.06$ g
2. $n(Mg) = \frac{1.68}{24.3} = 0.0691$ mol, $n(Mg) : n(MgO) = 1 : 1$
   $n(MgO) = 0.0691$ mol, $m(MgO) = 0.0691 \times 40.3 = 2.78$ g
3. $n(Na_2CO_3) = \frac{4.88}{106} = 0.0460$ mol, $n(Na_2CO_3) : n(NaHCO_3) = 1 : 2$
   $n(NaHCO_3) = 2 \times 0.0460 = 0.0920$ mol
   $m(NaHCO_3) = 0.0920 \times 84.0 = 7.73$ g
4. $n(Fe) = \frac{2.36}{55.9} = 0.0422$ mol, $n(Fe) : n(FeCl_3) = 1 : 1$
   $n(FeCl_3) = 0.0422$ mol, $m(FeCl_3) = 0.0422 \times 162 = 6.85$ g
5. a. $n(S) = \frac{2.28}{32.0} = 0.0713$ mol, $n(S) : n(FeS) = 1 : 1$, $n(FeS) = 0$ 0713 mol, $m(FeS) = 0.\ 0713 \times 87.9 = 6.27$ g
   b. $n(S) : n(Fe) = 1 : 1$, $n(Fe) = 0.\ 0713$ mol, $m(Fe)$ for the reaction to occur $= 0.\ 0713 \times 55.9 = 4.00$ g
   excess $m(Fe) = 5.74$ g – 4.00 g $= 1.74$ g
   1.76 using unrounded figures.

Activity 1D: Percentage composition (page 8)

1. a. $M(SO_2) = 32.0 + 16.0 \times 2 = 64.0$ g mol^{-1}
   % sulfur $= \frac{32.0}{64.0} \times 100 = 50.0$
   % oxygen $= \frac{32.0}{64.0} \times 100 = 50.0$
   b. $M(SO_3) = 32.0 + 16.0 \times 3 = 80.0$ g mol^{-1}
   % sulfur $= \frac{32.0}{80.0} \times 100 = 40.0$
   % oxygen $= \frac{48.0}{64.0} \times 100 = 60.0$
   c. $M(HNO_3) = 1.0 + 14.0 + 3.0 \times 16.0$
   $= 63.0$ g mol^{-1}
   % hydrogen $= \frac{1.0}{63.0} \times 100 = 1.59$
   % nitrogen $= \frac{14.0}{63.0} \times 100 = 22.2$
   % oxygen $= \frac{48.0}{63.0} \times 100 = 76.2$
   d. $M(C_3H_7COOH) = 4 \times 12.0 + 8 \times 1.0 + 2 \times 16.0$
   $= 88.0$ g mol^{-1}
   % carbon $= \frac{48.0}{88.0} \times 100 = 54.5$
   % hydrogen $= \frac{8.0}{88.0} \times 100 = 9.09$
   % oxygen $= \frac{32.0}{88.0} \times 100 = 36.4$
2. a. i. $\%(C) = \frac{12.0}{44.0} = 27.3$ ii. $\%(C) = \frac{24.0}{28.0} = 85.7$
   iii. $\%(C) = \frac{24.0}{46.0} = 52.2$
   b. i. $\%(N) = \frac{14.0}{63.0} = 22.2$ ii. $\%(N) = \frac{28.0}{148} = 18.9$
   iii. $\%(N) = \frac{28.0}{80.0} = 35.0$
3. a. Gypsum, $CaSO_4.2H_2O$
   $M(CaSO_4.2H_2O) = 40.1 + 32.0 + 4 \times 16.0 + 2 \times (2 \times 1.0 + 16.0) = 172$ g mol^{-1}
   $M(H_2O) = 2 \times 1.0 + 16.0 = 18.0$ g mol^{-1}
   Percentage of water $= \frac{2 \times 18.0}{172.1} \times 100 = 20.9\%$
   b. Washing soda, $Na_2CO_3.10H_2O$
   $M[(Na_2CO_3).10H_2O] = 2 \times 23.0 + 12.0 + 3 \times 16.0 + 10 \times (2 \times 1.0 + 16.0) = 286$ g mol^{-1}
   $M(H_2O) = 2 \times 1.0 + 16.0 = 18.0$ g mol^{-1}
   Percentage of water $= \frac{180.0}{286.0} \times 100 = 62.9\%$

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