National 5 Chemistry

Unit 1 Chemical Changes & Structure

Part 2

Summary Notes

Topic 3

Formulae and Reacting Quantities

H_2O NH_3

CCl_4 CO_2

Learning Outcomes

Chemical Formulae

- Compound names are derived from the names of the elements from which they are formed. Most compounds with a name ending in '-ide' contain the two elements indicated. The ending '-ite' or '-ate' indicates that oxygen is also present.
- Chemical formulae can be written for two element compounds using valency rules and a Periodic Table.
- Roman numerals can be used, in the name of a compound, to indicate the valency of an element.
- The chemical formula can also be determined from names with prefixes.
- The chemical formula of a covalent molecular substance gives the number of each type of atom present in a molecule.
- The formula of a covalent network gives the simplest ratio of each type of atom in the substance.
- Ions containing more than one type of atom are often referred to as group ions.
- Chemical formulae can be written for compounds containing group ions using valency rules and the data booklet.
- Ionic formulae give the simplest ratio of each type of ion in the substance and can show the charges on each ion, if required.
- In formulae, charges must be superscript and numbers of atoms/ions must be subscript.

Calculations involving the mole and balanced equations

- Chemical equations, using formulae and state symbols, can be written and balanced.
- The mass of a mole of any substance, in grams (g), is equal to the gram formula mass and can be calculated using relative atomic masses.
- Calculations can be performed using the relationship between the mass and the number of moles of a substance.
- A solution is formed when a solute is dissolved in a solvent.
- For solutions, the mass of solute (grams or g), the number of moles of solute (moles or mol), the volume of solution (litres or l) or the concentration of the solution (moles per litre or mol l^{-1}) can be calculated from data provided.
- Given a balanced equation, the mass or number of moles of a substance can be calculated given the mass or number of moles of another substance in the reaction.

Percentage Composition

- The percentage composition of an element in any compound can be calculated from the formula of the compound.

Naming Compounds

If a compound contains just **two elements** the compound name consists of the names of both elements but the last part of the second name becomes **–ide**.

e.g. **magnesium** and **oxygen** make **magnesium oxide**

If a compound contains **more than two elements and one of them is oxygen** the compound name consists of the names of both the other elements but the last part of the second name becomes **–ate** or **–ite** depending on the number of oxygen atoms.

e.g. **copper**, **sulfur** and **oxygen** make **copper sulfate**.

Chemical Formulae

The chemical formulae for any substance gives the simplest ratio of atoms/ions present.

e.g. H_2O contains 2 hydrogen atoms and 1 oxygen atom

Reminder: Molecules made up of only two atoms are called **diatomic** molecules, e.g. hydrogen chloride, HCl (one hydrogen atom and one chlorine atom), and carbon monoxide, CO (one carbon atom and one oxygen atom). There are 7 diatomic **elements** you must remember. As they are diatomic, the chemical formulae must include a '2' after the symbol e.g. hydrogen (H_2), nitrogen (N_2), oxygen (O_2), and the group 7 elements (F_2, Cl_2, Br_2, I_2).

Writing Chemical Formula

Prefixes

Some compounds have meaningful names which contain indicate what the chemical formula is by using one or more of the following prefixes; **mono-, di-, tri-, tetra-, penta– and hexa-.**

The name of the compound gives its chemical formula, for example carbon **di**oxide has the formula CO_2.

Prefix	Meaning	Name of Compound	Formula
mono-	one	Carbon monoxide	CO
di-	two	Sulfur dioxide	SO_2
tri-	three	Sulfur trioxide	SO_3
tetra-	four	Silicon tetrachloride	$SiCl_4$
penta-	five	Phosphorous pentaiodide	PI_5
hexa-	six	Tungsten hexachloride	WCl_6

Valency Method

(i) Simple two element covalent compounds

The formula for compounds whose names do not have prefixes are worked out by, first of all, giving each element a valency number.

The **valency number** depends on the **group** where the element is found in the Periodic Table and directly relates to the **number of unpaired electrons**.

Group	1	2	3	4	5	6	7	0
Valency	1	2	3	4	3	2	1	0

Magnesium has a valency of 2, because it is in Group 2 while oxygen also has a valency of 2, because it is in Group 6.

To determine the chemical formula for a compound you then follow these simple steps.

1. Write down the symbols for the two elements in the same order as the compounds name.
2. Write down the element's valency above its symbol.
3. Cross the valencies.
4. Simplify down the valencies if you can.
5. Write the chemical formula.

Example 1: Hydrogen Sulfide

Example 2: Carbon Sulfide

(ii) Simple two element ionic compounds

An **ionic formula** shows the charges of the ions as well as the proportion of each.

The **total charge** in an ionic formula should be **'zero'**.

To determine the chemical formula for a compound you then follow these simple steps.

1. Write down the ion symbols for the two elements in the same order as the compounds name.
2. Write down the element's valency above its symbol.
3. Cross the valencies.
4. Simplify down the valencies if you can.
5. Write the ionic formula.
6. Ion with its charge must go in brackets if there is more than one of its kind.

Example 1: Sodium Chloride

Double check that the overall charge is zero:

Example 2: Aluminium Oxide

Double check that the overall charge is zero:

(iii) Simple ionic compounds involving transition metals

Some elements, like the transition metals and some of the metals in Group 4 onwards, can have **more than** one valency number. This is given in the compound's name by a **Roman Numeral.**

Roman Numeral	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)
Valency	1	2	3	4	5	6	7

The chemical formula is then worked out using the valency method as described for simple two element ionic compounds.

Example — Copper(I) oxide

(iv) Group ions (Compounds with more than two elements)

Compounds with more than two elements contain **group ions.**

Group ions are groups of atoms which carry a charge and **stay together** during chemical reactions. The sulfate ion is written; SO_4^{2-}

Group ions have a valency number which covers the whole ion. This is equal to the **size** of its charge. So the valency of the sulfate ion is **2**.

The valencies of the group ions can be found on page 8 of your Data Booklet.

Group ion	Formula	Valency
Carbonate	CO_3^{2-}	2
Nitrate	NO_3^-	1
Sulfate	SO_4^{2-}	2
Hydroxide	OH^-	1
Ammonium	NH_4^+	1

The chemical formula is then worked out using the valency method as described for simple two element ionic compounds.

Example 1: Sodium sulfate

*When there is more than one of the same group ion in a compound we must put the group ion inside brackets.

Example 2: Magnesium hydroxide

Writing Chemical Equations

Chemical Equations

(i) Writing chemical equations

Word Equations

A word equation is used to show the chemicals being used in a reaction (**reactants**) and the new substances being made or produced in a reaction (**products**).

Example:

When calcium carbonate reacts with hydrochloric acid, calcium chloride, carbon dioxide and water are produced.

Written as a word equation this would be:

$$\underbrace{\text{Calcium carbonate + hydrochloric acid}}_{\textbf{Reactants}} \longrightarrow \underbrace{\text{calcium chloride + carbon dioxide + water}}_{\textbf{Products}}$$

If the names of the chemicals in a word equation are replaced with their formulae, the word equation becomes a **chemical equation.**

The above word equation would become:

calcium carbonate + hydrochloric acid ⟶ calcium chloride + carbon dioxide + water

$$CaCO_3 + HCl \longrightarrow CaCl_2 + CO_2 + H_2O$$

The same elements must appear on both sides of the chemical equation.

Writing Chemical Equations

State symbols are used in chemical equations to indicate the physical state of the chemicals being used.

State	Symbol
Solid	s
Liquid	*l*
Gas	g
Solution	aq

E.g. calcium carbonate + hydrochloric acid $\longrightarrow$ calcium chloride + carbon dioxide + water

$CaCO_3(s)$ + $HCl(aq)$ $\longrightarrow$ $CaCl_2(aq)$ + $CO_2(g)$ + $H_2O(l)$

(ii) Balancing chemical equations

A chemical equation must have the same elements on each side.

A **balanced** chemical equation must have the same number of atoms of each element on each side.

Example 1

Methane + Oxygen $\longrightarrow$ Carbon dioxide + Water

CH_4 + O_2 $\longrightarrow$ CO_2 + H_2O

The Chemical Mole

Gram Formula Mass

The mass of one mole of a substance, in **grams (g)**, is known as the **gram formula mass (GFM).**

The GFM is obtained by adding together all the **relative atomic masses** of each atom or ion in the chemical formula.

Relative atomic masses are given on page 7 of the data booklet.

Example 1: Determine the gram formula mass of sodium chloride, NaCl

Example 2: Determine the gram formula mass of magnesium nitrate, $Mg(NO_3)_2$

Remember - everything inside the brackets is multiplied by the number outside

Mole Calculations

The Mole

Moles are small animals which live underground, famous for their burrowing skills - but to a chemist a mole is the basic unit of measurement. It is a certain number of chemical units. A **mole** in chemistry is defined as the relative atomic mass in grams. Water has a GFM of 18 so 1 mole of water is 18 g. Calcium carbonate, $CaCO_3$, has a GFM of 100 so 1 mole of calcium carbonate is 100 g.

Mole Calculations

Once you are able to calculate the mass of 1 mole of a substance you can calculate the mass of an exact number of moles. The relationship is given on page 3 of the data booklet.

Mass (g)

Number of moles $\rightarrow$ $$n = \frac{m}{GFM}$$

Gram formula mass (g)

At National 5 you will be required to use this relationship and rearrange it to solve problems.

$$\mathbf{n = \frac{m}{GFM}} \qquad \mathbf{m = n \times GFM} \qquad \mathbf{GFM = \frac{m}{n}}$$

<u>Calculating mass using:</u> m = n x GFM

Example: What is the mass of 2 moles of sodium chloride, NaCl?

Step 1	Write the formula for sodium chloride:	NaCl
Step 2	Calculate the GFM:	58·5g
Step 3	Calculate the mass using the moles relationship:	m = n x GFM
		m = 2 x 58·5
		m = 117 g

<u>Calculating moles using:</u> n = m ÷ GFM

Example: How many moles are there in 10 g of calcium carbonate?

Step 1	Write the formula for calcium carbonate:	$CaCO_3$
Step 2	Calculate the gram formula mass:	(1 x 40) + (1 x 12) + (3 x 16) = 100g
Step 3	Calculate the moles using the relationship:	n = m ÷ GFM
		n = 10 ÷ 100
		n = 0·1 moles

<u>Calculating GFM using:</u> GFM = m ÷ n

Example: What is the mass of one mole of a gas if 0.25 moles has a mass of 7 g?

In this type of calculation you can just move straight on and set out the relationship.

$$\text{GFM} = \frac{m}{n}$$

$$= \frac{7}{0.25}$$

$$= 28\text{g}$$

Moles and Concentration

Concentration

Many chemical reactions are not carried out with solids or pure liquids but use solutions where a substance has been dissolved. The **concentration** of a solution is expressed in terms of the **number of moles** of the solute in **one litre** of solution. Concentration has units of **moles per litre** or **mol l^{-1}.**

If you have 1 litre of solution and it contains 1 mole of solute then the concentration will be 1 mol l^{-1}. The concentration of any solution can be calculated using a relationship. The relationship is given on page 3 of the data booklet.

Concentration (mol l^{-1})

Number of moles

$$n = CV$$

Volume (l)

At National 5 you will be required to use this relationship and rearrange it to solve problems.

$$\mathbf{C = \frac{n}{V}} \qquad \mathbf{n = C \times V} \qquad \mathbf{V = \frac{n}{C}}$$

Calculations Involving Concentration

<u>Calculating moles using:</u> $n = C \times V$

Example: How many moles of sodium hydroxide are there in 200 cm^3 of a 0·4 mol l^{-1} solution?

Step 1 Change the volume from cm^3 to litres (÷1000): 200 cm^3 = 0·2 l

Step 2 Calculate the number of moles:

n = C x V
n = 0·4 x 0·2
n = 0·08 moles

<u>Calculating concentration using:</u> $C = n \div V$

Example: A 50 cm^3 sample of hydrochloric acid contains 0·1 moles. What is the concentration of the acid?

Step 1 Change the volume from cm^3 to litres (÷1000): 50 cm^3 = 0·05 l

Step 2 Calculate the concentration:

C = n ÷ V
C = 0·1 ÷ 0·05
C = 2 mol l^{-1}

<u>Calculating volume using:</u> $V = n \div C$

Example: What volume of a 2 mol l^{-1} solution of potassium chloride contains 0·5 moles of solute?

In this type of calculation you can just move straight on and set out the relationship.

V = n ÷ C
V = 0·5 ÷ 2
V = 0·25 l or 250 cm^3

Converting cm^3 into litres ÷ 1000

Converting litres into cm^3 x 1000

Remember: $\boxed{n = \frac{m}{GFM}}$ **and** $\boxed{n = CV}$

Calculations from Balanced Equations

Balanced Equation Calculations

A balanced equation gives **the number of moles** of each reactant and product.

Since the **mass of one mole of any substance is expressed in grams**, it is possible to use the balanced equation and the mass for the relevant number of moles for the reaction in calculations. It is then possible to work out what mass of a product would be produced from any given mass of reactant.

Example

Calculate the mass of water produced on burning **4g** of methane (CH_4).

Step 1 Write the balanced equation.

Step 2 Write down the number of moles of each substance that reacts.

Step 3 Work out which reactant and product you need to use (from the question).

Step 4 Work out the **total masses** for the substances you have just identified.

Step 5 Work out how much of the product identified would form from 1g of the identified reactant (remember if you do something to the left hand side, you **must** do the same to the right hand side).

Step 6 Using the fraction you have just worked out, work out the mass produced from the mass asked about in the question.

Answer

Step 1		$\mathbf{CH_4}$	+ $2O_2$	CO_2	+ $\mathbf{2H_2O}$	**(bold is step 3)**
Step 2		**1 mol**	2 mol	1 mol	**2 mol**	
Step 4		16g	$\longrightarrow$		36g	
	÷ 16					
Step 5		1g	$\longrightarrow$		$\frac{36}{16}$	
	x 4					
Step 6		4g	$\longrightarrow$		$\frac{36}{16} \times 4$ = 9g	

Percentage composition

It is important for chemists to know the percentage of an element in any given compound. They do this using the equation:

$$\% \text{ by mass} = \frac{m}{GFM} \times 100$$

This can be found on page 3 of the data book

Example 1 What is the percentage of iron in iron(III) oxide?

Step 1 Calculate the GFM of the ore

Fe_2O_3

3 x 16

<u>2 x 56</u>

160 g

Step 2 Calculate the total mass of the metal in the formula.

Fe_2O_3 2 x 56 = 112g

Step 3 Divide the mass of the metal by the GFM and multiply by 100%

$$\% \text{ by mass} = \frac{112}{160} \times 100$$

= **70%**

Example 2 What is the mass of hydrogen in water (H_2O)?

H_2O

1 x 16 = 16

2 x 1 = 2

18g

mass of H_2 = 2g

$$\% \text{ by mass} = \frac{\text{mass of } H_2}{\text{gfm of } H_2O} \times 100$$

$$= \frac{2}{18} \times 100$$

= **11.11%**

Topic Questions

Exercise 1

1. Work out the chemical formula for each of the following compounds.

a)	Sodium bromide	b)	Magnesium chloride
c)	Aluminium oxide	d)	Lithium sulfide
e)	Magnesium nitride	f)	Potassium oxide

2. Work out the chemical formula for the following compounds.

a)	Copper(I) chloride	b)	Zinc(II) fluoride
c)	Nickel(II) sulfate	d)	Copper(II) oxide

3. Work out the chemical formula for the following compounds.

a)	Sodium nitrate	b)	Magnesium carbonate
c)	Potassium sulfate	d)	Calcium carbonate
e)	Magnesium nitrate	f)	Calcium hydroxide
g)	Aluminium sulfate	g)	Ammonium sulphate

4. Work out the ionic formula for each of the following compounds.

a)	Lithium chloride	b)	Calcium fluoride
c)	Potassium sulfide	d)	Magnesium oxide
e)	Aluminium chloride	f)	Magnesium nitride

5. Work out the ionic formula for each of the following, remember to refer to page in the data booklet.

a)	Sodium sulfate	b)	Potassium nitrate
c)	Calcium carbonate	d)	Magnesium hydroxide
e)	Lithium carbonate	f)	Ammonium hydroxide
g)	Sodium sulfite	h)	Copper(II) carbonate
i)	Tin(II) chloride	j)	Lead(II) nitrate

Exercise 2

1. Write chemical equations for each of the following reactions.

   a) Copper(II) oxide reacting with hydrochloric acid to form copper(II) chloride and water.

   b) Magnesium hydroxide reacting with sulfuric acid to form magnesium sulfate and water.

   c) Lithium carbonate reacting with hydrochloric acid to form lithium carbonate, carbon dioxide and water.

2. Balance the following chemical equations.

   a) $CH_4 \quad + \quad O_2 \longrightarrow CO_2 \quad + \quad H_2O$

   b) $N_2 \quad + \quad H_2 \longrightarrow NH_3$

   c) $Fe_2O_3 \quad + \quad H_2 \longrightarrow Fe \quad + \quad H_2O$

   d) $AgNO_3 \quad + \quad BaCl_2 \longrightarrow Ba(NO_3)_2 \quad + \quad AgCl$

3. Calculate the mass of 1 mole of each of the following substances.

   a) Chlorine, Cl_2

   b) Nitrogen, N_2

   c) Carbon monoxide, CO

   d) Sodium fluoride, NaF

   e) Potassium sulfate, K_2SO_4

4. Calculate the mass of each of the following substances. Show your working clearly.

   a) 0·5 moles of water, H_2O

   b) 4 moles of hydrogen chloride, HCl

   c) 2·5 moles of carbon dioxide, CO_2

   d) 0·2 moles of magnesium hydroxide, $Mg(OH)_2$

   e) 0·01 moles of potassium permanganate, $KMnO_4$

   f) 1·5 moles of iron(III) oxide, Fe_2O_3

Exercise 3

1. Calculate the number of moles in each of the following substances.

a) 20 g of calcium, Ca

b) 14 g of nitrogen, N_2

c) 280 g of carbon monoxide, CO

d) 10·1 g of potassium nitrate, KNO_3

e) 8·5 g of sodium nitrate, $NaNO_3$

f) 6·6 g of ammonium sulfate, $(NH_4)_2SO_4$

g) 16 g of iron(III) oxide, Fe_2O_3

h) 55·5 g of calcium chloride, $CaCl_2$

i) 31·2 g of aluminium hydroxide, $Al(OH)_3$

j) 1·16 g of lithium phosphate, Li_3PO_4

2. Calculate the number of moles of solute dissolved in each of the following solutions:

a) 500 cm^3 of a 0·5 mol l^{-1} solution of sodium chloride

b) 2 litres of a 0·2 mol l^{-1} solution of hydrochloric acid

c) 50 cm^3 of a 0·1 mol l^{-1} solution of potassium hydroxide

d) 2·5 cm^3 of a 4 mol l^{-1} solution of nitric acid

e) 10 cm^3 of a 0·2 mol l^{-1} solution of potassium permanganate.

3. Calculate the concentration of:

a) 250 cm^3 of a solution containing 0·5 moles of lithium hydroxide

b) 2 litres of a solution containing 4 moles of potassium bromide

c) 20 cm^3 of a solution containing 0·01 moles of copper(II) sulfate.

4. Calculate the volume of:

a) a 0·5 mol l^{-1} solution containing 0·1 moles of sodium chloride

b) a 2 mol l^{-1} solution containing 0·5 moles of sulfuric acid

c) a 0·1 mol l^{-1} solution containing 1 moles of ammonium nitrate.

Exercise 4

1. Name the compounds which contain the following elements:
   a) Magnesium and sulfur
   b) Chlorine and sodium
   c) Calcium, carbon and oxygen

2. Which elements are in the following compounds:
   a) Lithium carbonate
   b) Lead nitrate
   c) Copper sulphide

3. Complete the following table using the name of the compound to work out the formula:

Name	Formula
Carbon monoxide	
	PF_5
Sulfur dioxide	
	N_2O
Dinitrogen trisulfide	
	P_4O_{10}

4. Use the valency method to help write the formula of the following compounds:
   a) Boron hydride
   b) Phosphorus hydride
   c) Sodium chloride
   d) Calcium oxide
   e) Ammonium Sulfate
   f) Beryllium hydroxide
   g) Silver (I) nitrate

Exercise 5

1. Write the **word** equation for the following reactions:

   a) Copper, sodium nitrate and carbon dioxide are produced from a reaction between sodium carbonate solution and copper (II) nitrate solution.

   b) Copper sulphate, carbon dioxide and water are produced when sulfuric acid reacts with copper carbonate.

   c) Methane burns in air to produce carbon dioxide and water.

2. Balance the following equations:

   a) $Mg + O_2 \longrightarrow MgO$

   b) $P + O_2 \longrightarrow P_2O_5$

   c) $C_2H_4 + O_2 \longrightarrow CO_2 + H_2O$

   d) $SO_2 + O_2 \longrightarrow SO_3$

   e) $Cu + AgNO_3 \longrightarrow Ag + Cu(NO_3)$

3. Calculate the **gram formula mass** of calcium nitrate, $Ca(NO_3)_2$.

4. How many **moles** are there in 2480 g of copper (II) carbonate?

5. Calculate the number of moles of water in 162 g of water.

6. What is the mass of 0.75 moles of aluminium oxide?

7. What is the concentration of a solution of sodium chloride which contains 0.5 moles dissolved in 250 cm^3 of water.

8. Write the balanced equation for the reaction between sodium with water, producing sodium hydroxide and hydrogen.

9. What mass of sulfur must burn to produce 38 g of sulfur dioxide?

   ($S + O_2 \longrightarrow SO_2$)

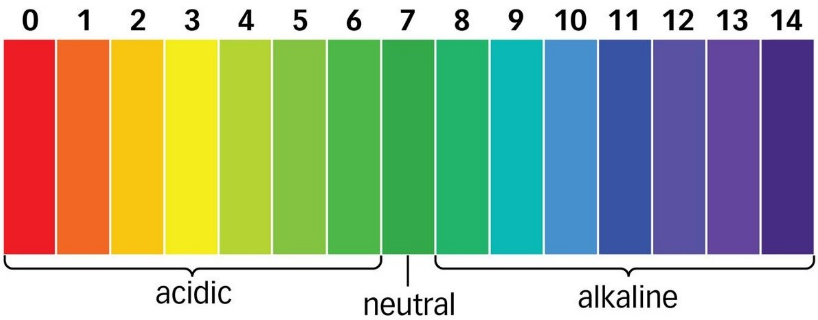
10. Calculate the number of moles in 25 g of calcium carbonate, $CaCO_3$

Exercise 6

1. Calculate the percentage by mass of iron in haematite, Fe_2O_3.
2. Calculate the percentage by mass of sodium in sodium carbonate, Na_2CO_3.
3. Calculate the percentage by mass of copper in malachite, $Cu_2CO_3(OH)_2$.
4. Calculate the mass of aluminium which could be obtained from 500 g of aluminium oxide, Al_2O_3.
5. Calculate the mass of lead which could be obtained by the electrolysis of 50 kg of molten lead bromide, $PbBr_2$.
6. Calculate the percentage by mass of potassium in potassium nitrate, KNO_3.
7. Calculate the percentage by mass of nitrogen in calcium nitrate, $Ca(NO_3)_2$.
8. Calculate the percentage by mass of nitrogen in ammonium nitrate, NH_4NO_3.
9. Calculate the percentage by mass of phosphorus in ammonium phosphate, $(NH_4)_3PO_4$.

Topic 4

Acids and Bases



Learning Outcomes

pH

- The pH scale is an indication of the hydrogen ion concentration and runs from below 0 to above 14.
- A neutral solution has equal concentrations of $H^+(aq)$ and $OH^-(aq)$ ions.
- Water is neutral as it dissociates according to the equation: $H_2O(\ell) \rightleftharpoons H^+(aq) + OH^-(aq)$

  producing equal concentrations of hydrogen and hydroxide ions. At any time, only a few water molecules are dissociated into free ions.
- The symbol indicates that a reaction is reversible and occurs in both directions.
- Acidic solutions have a higher concentration of $H^+(aq)$ ions than $OH^-(aq)$ and have a pH below 7.
- Alkaline solutions have a higher concentration of $OH^-(aq)$ ions than $H^+(aq)$ ions and have a pH above 7.
- Dilution of an acidic solution with water will decrease the concentration of $H^+(aq)$ and the pH will increase towards 7.
- Dilution of an alkaline solution with water will decrease the concentration of $OH^-(aq)$ and the pH will decrease towards 7.
- Soluble non-metal oxides dissolve in water forming acidic solutions.
- Soluble metal oxides dissolve in water to form alkaline solutions:

  metal oxide + water $\longrightarrow$ metal hydroxide

- Metal oxides, metal hydroxides, metal carbonates and ammonia neutralise acids and are called bases. Those bases that dissolve in water form alkaline solutions.

Neutralisation reactions

- A neutralisation reaction is one in which a base reacts with an acid to form water. A salt is also formed in this reaction.
- Equations can be written for the following neutralisation reactions:
-

  a metal oxide + an acid $\longrightarrow$ a salt + water
  a metal hydroxide + an acid $\longrightarrow$ a salt + water
  a metal carbonate + an acid $\longrightarrow$ a salt + water + carbon dioxide

- The name of the salt produced depends on the acid and base used. Hydrochloric acid produces chlorides, sulfuric acid produces sulfates and nitric acid produces nitrates.
- Spectator ions are ions that remain unchanged by the reaction.
- Reaction equations can be used to identify spectator ions.
- For neutralisation reactions, equations can be written omitting spectator ions:

  $2H^+(aq) + O^{2-}(s)$ $H_2O(\ell)$ for metal oxides
  $H^+(aq) + OH^-(aq)$ $H_2O(\ell)$ for metal hydroxides
  $2H^+(aq) + CO_3^{2-}(aq)$ $H_2O(\ell) + CO_2(g)$ for aqueous metal carbonates
  $2H^+(aq) + CO_3^{2-}(s)$ $H_2O(\ell) + CO_2(g)$ for insoluble metal carbonates

- In an acid-base titration, the concentration of the acid or base is determined by accurately measuring the volumes used in the neutralisation reaction. An indicator can be added to show the end-point of the reaction.

- Given a balanced equation for the reaction occurring in any titration:
  - the concentration of one reactant can be calculated given the concentration of the other reactant and the volumes of both solutions
  - the volume of one reactant can be calculated given the volume of the other reactant and the concentrations of both solutions.

Neutralisation reactions can be used to prepared soluble salts

- Titration can be used to produce a soluble salt. Once the volumes of acid and alkali have been noted, the reaction can be repeated without the indicator to produce an uncontaminated salt solution. The solution can then be evaporated to dryness.
- Insoluble metal carbonates and insoluble metal oxides can be used to produce soluble salts. Excess base is added to the appropriate acid, the mixture is filtered and the filtrate evaporated to dryness

The pH scale

The pH scale ranges from below 0 to above 14 and is used to measure the acidity or alkalinity of a solution. This can be done using a pH meter which gives an electronic reading or using an **indicator** which can change colour depending on the pH value. The colour can be matched on the pH colour chart to indicate the pH number.

Acidic solutions have a pH that is less than 7.

Alkaline solutions have a pH that is greater than 7.

Neutral solutions have a pH value of 7.

pH	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Type of Solution	**Acid** **increasing acidity**							**Neutral**	**Alkali** **increasing alkalinity**						

Explaining pH

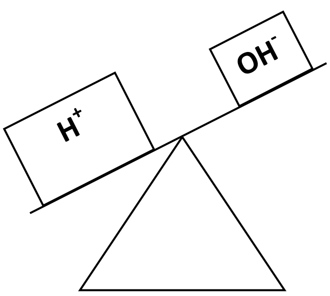
Water is a neutral substance which mainly exists as water molecules. Water is an example of a non-metal oxide which is formed from hydrogen and oxygen. However, a very few water molecules break up (dissociate) to produce one hydrogen ion, H^+, and one hydroxide ion, OH^-.

$$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq)$$

many water molecules **very few ions**

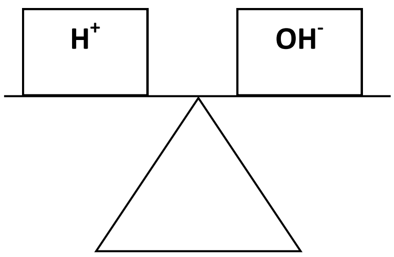
Since water is mainly made of molecules and contains only a few ions it is a poor conductor of electricity. Since water contains an equal concentration of hydrogen and hydroxide ions - in other words it is neutral.

An acidic solution is one which contains a greater concentration of hydrogen ions compared to hydroxide ions while an alkaline solution will have a greater concentration of hydroxide ions compared to hydrogen ions.



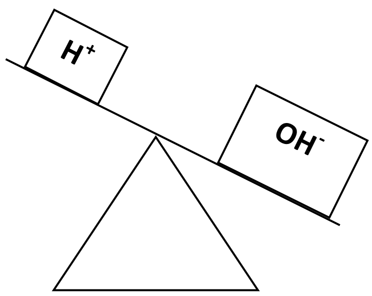
Acid

Greater Concentration of H^+ than OH^-



Neutral

Equal Concentration of H^+ and OH^-



Alkali

Greater Concentration of OH^- than H^+

The pH scale

Dilution

When a solution is diluted the concentration decreases. As an acid is diluted the pH increases as the concentration of hydrogen ions decreases. As an alkali is diluted the pH value decreases since the concentration of hydroxide ions decreases. Adding sufficient water to either an acidic or alkaline solution will produce a solution of pH value 7.

Common Acids

Acidic solutions are made by dissolving non-metal oxides in water such as carbon dioxide and sulfur dioxide. The five most common laboratory acids are listed in the table.

Name of Acid	Chemical Formula
Hydrochloric acid	HCl
Nitric acid	HNO_3
Sulfuric acid	H_2SO_4
Ethanoic acid	CH_3COOH
Phosphoric acid	H_3PO_4

Acid Conductivity

Acidic solutions contain non-metal elements and are formed when covalent substances such as sulfur dioxide dissolve. All acidic solutions will conduct electricity since they all contain the hydrogen ion, H^+.

When acidic solutions are electrolysed (undergo electrolysis) hydrogen gas is produced at the negative electrode.

During this process hydrogen ions gain electrons and form hydrogen atoms which then form molecules of hydrogen gas. The following ion electron equation shows this process:

$$\underset{\text{Hydrogen ions}}{2H^+(aq)} + 2e^- \longrightarrow \underset{\text{Hydrogen gas}}{H_2(g)}$$

The hydrogen gas produced can be tested since it will burn with a pop.

Common Alkalis

Alkaline solutions are made by dissolving **soluble** metal oxides in water. **Insoluble** metal oxides such as copper oxide will **not** affect the pH of water.

Some common alkalis are listed in the table below.

Name of Alkali	Chemical Formula	Ions Present
lithium hydroxide	$LiOH$	Li^{+} and OH^{-}
sodium hydroxide	$NaOH$	Na^{+} and OH^{-}
Potassium hydroxide	KOH	K^{+} and OH^{-}
Calcium hydroxide	$Ca(OH)_2$	Ca^{2+} and OH^{-}

Bases

Any substance which neutralises an acid is called a **base**. A base is a substance which accepts hydrogen ions from acids to form water. Common bases are **metal oxides**, **metal hydroxides** and **metal carbonates** and **ammonia**.

An alkali is a soluble base. For example sodium hydroxide is a base and also an alkali since it is soluble. Copper(II) oxide is a base but is not an alkali since it is insoluble. The data booklet can be used to determine if a base is soluble (page 8). When an acid is neutralised by a base a salt is always formed along with water.

Bases: **Metal Oxides**

Metal Hydroxides

Metal Carbonates

Ammonia

Alkalis : **Soluble Bases**

Neutralisation

When alkali is added to an acid the pH of the acid increases (moves towards 7). When an acid is added to an alkali the pH of the alkali decreases (moves towards 7). Reacting an acid and a base is an example of a neutralisation reaction.

Products of Neutralisation

An acid is a substance that has a greater concentration of hydrogen ions than hydroxide ions, while alkaline solutions have a greater concentration of hydroxide ions than hydrogen ions. Neutral solutions, like water, have an equal concentration of hydrogen ions and hydroxide ions.

During a neutralisation reaction the hydrogen ions (H^+) from the acid and the hydroxide ions (OH^-) from the alkali react to form water.

$$H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$$

During a neutralisation reaction a substance known as a salt is also formed with water.

Neutralisation Equations:

a metal oxide + an acid $\longrightarrow$ a salt + water
a metal hydroxide + an acid $\longrightarrow$ a salt + water
a metal carbonate + an acid $\longrightarrow$ a salt + water + carbon dioxide
ammonia + an acid $\longrightarrow$ a salt

A salt is a substance in which the hydrogen ions of an acid have been replaced by a metal ion (or ammonium ion). The name of the salt comes from the name of the base and acid which it formed from.

Naming Salts

Salts are produced when acids are neutralised and the name of the salt depends on the acid and the alkali used in the neutralisation reaction. The name of a salt has two parts.

Sodium **Chloride**

from base *from acid*

All bases contain either a metal or ammonia. The metal or ammonium provides the first part of the salt's name and the acid provides the second part of the name.

Example 1: Sodium hydroxide reacts with nitric acid to produce water and a salt.

The salt is called: Sodium nitrate

Name of alkali	Salt name starts with ….
Sodium hydroxide	Sodium ……
Potassium hydroxide	Potassium …..
Magnesium hydroxide	Magnesium …..

Name of acid	Salt name ends with ….
Hydrochloric acid	…… chloride
Sulfuric acid	….. sulfate
Nitric acid	….. nitrate

Example 2: Potassium hydroxide reacts with sulfuric acid to produce water and a salt. The salt in this case would be potassium sulfate.

Alkali	Acid	Salt Produced
sodium hydroxide	**hydrochloric acid**	**sodium chloride**
lithium hydroxide	**sulfuric acid**	**lithium sulfate**
calcium hydroxide	**nitric acid**	**calcium nitrate**
potassium hydroxide	**phosphoric acid**	**potassium phosphate**

Neutralising with insoluble bases:

Metal oxides are examples of bases and can therefore be used to neutralise an acid. When reacting copper (II) oxide with sulfuric acid you first of all react the copper (II) oxide to ensure that all the acid is neutralised before then filtering the excess copper (II) oxide to leave the salt solution. The salt crystals can then be formed through evaporation.

Ionic Equations

We know that when an acid reacts with an alkali, the acid is being neutralised, but what part of the acid reacts with what part of the alkali?

e.g. hydrochloric acid + sodium hydroxide ⟶ sodium chloride + water

$$HCl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + H_2O(l)$$

If we write down all the ions and molecules present:

$$\mathbf{H^+(aq) + Cl^-(aq) + Na^+(aq) + OH^-(aq) \longrightarrow Na^+(aq) + Cl^-(aq) + H_2O(l)}$$

This is known as an **ionic equation.**

Ionic Equations

We can see that the sodium (Na^+) and chloride (Cl^-) ions are present at the start and end of the reaction and don't change. **These are called spectator ions and can be removed (omitted) from our equation,** so that we are only showing the species actually reacting.

The equation would now look like this:

$$H^+(aq) \quad + \quad OH^-(aq) \longrightarrow H_2O(l)$$

This shows that when acids are neutralised by alkalis, the hydrogen ions from the acid and the hydroxide ions from the alkali join to form water.

Spectator Ions

Spectator ions are present in a reaction mixture but don't take part. Spectator ions appear unchanged on both sides of a chemical equation. As a result, they are sometimes left out (omitted) in the chemical equation.

Example: Nitric acid (HNO_3) reacting with Lithium hydroxide (LiOH)

Word Equation: Nitric Acid + Lithium Hydroxide $\longrightarrow$ Lithium Nitrate + Water

Chemical Equation: $HNO_3(aq) + LiOH(aq) \longrightarrow LiNO_3(aq) + H_2O(l)$

Ionic Equation: $H^+(aq) + NO_3^-(aq) + Li^+(aq) + OH^-(aq) \longrightarrow Li^-(aq) + NO_3^-(aq) + H_2O(l)$

Equation omitting spectator ions: $\boxed{H^+(aq) \quad + \quad OH^-(aq) \longrightarrow H_2O(l)}$

Omitting means to leave out.

For neutralisation reactions, the following would be the resultant equation after omitting the spectator ions:

$2H^+(aq) + O^{2-}(s) \longrightarrow H_2O(l)$ for metal oxides
$H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$ for metal hydroxides
$2H^+(aq) + CO_3^{2-}(aq) \longrightarrow H_2O(l) + CO_2(g)$ for aqueous metal carbonates
$2H^+(aq) + CO_3^{2-}(s) \longrightarrow H_2O(l) + CO_2(g)$ for insoluble metal carbonates

Titrations

In an acid-base titration, the unknown concentration of the acid or base is determined by accurately measuring the volumes used during the neutralisation reaction.

An **indicator** can be added to show the end-point of the reaction (a colour change will occur).

A titration is used to determine, accurately, the volumes of solution required to reach the end-point of a chemical reaction. Soluble salts are produced as a result.

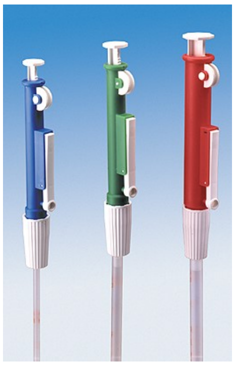
- Titre volumes must be within 0·2 cm^3 to be considered **concordant.**
- Solutions of accurately known concentration are known as standard solutions.

Titration Equipment

Pipette

The pipette is an instrument which measures a specific volume of liquid very accurately. Different sizes are available for different volumes. In school we have 2 types of pipette. Your teacher will demonstrate how to use a pipette.

Glass Pipettes

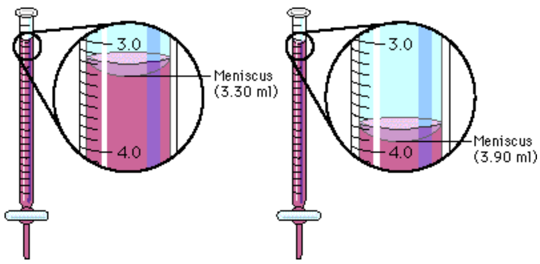


Pipette Fillers

Plastic Pipette

Burette

The burette is an instrument which measures varying volumes of solutions very accurately. Normally the scale on a burette is in graduations of 0·1cm^3. The scale starts at 0·0 cm^3 from the top to 50·0 cm^3 at the bottom. (This is the opposite to a measuring cylinder.) It is important that you always ensure you read a burette at **eye level** otherwise you will not take accurate readings.



Reading a Burette

Titration Calculations

The concentration of an acid or alkali can be calculated using volumetric titration results.

An acid will exactly neutralise an alkali and vice versa when the following condition is satisfied.

$$\frac{\textbf{C}\text{oncentration of acid} \times \textbf{V}\text{olume of acid}}{\textbf{n}\text{umber of moles of acid}} = \frac{\textbf{C}\text{oncentration of alkali} \times \textbf{V}\text{olume of alkali}}{\textbf{n}\text{umber of moles of alkali}}$$

This relationship can be written as: $$\frac{C_1V_1}{n_1} = \frac{C_2V_2}{n_2}$$

This relationship is stated on page 3 of the National 5 data booklet.

When using this relationship there is no need to change the volume into litres since you would be dividing both sides by 1000.

The number of moles of the acid and alkali is found by looking at the balanced chemical equation.

Example 1:

12·5 cm^3 of 1 mol l^{-1} hydrochloric acid is required to neutralise 10·0 cm^3 of sodium hydroxide. Calculate the concentration of the sodium hydroxide solution.

$$HCl(aq) + NaOH(aq) \longrightarrow NaCl + H_2O(l)$$

$$\frac{C_1V_1}{n_1} = \frac{C_2V_2}{n_2}$$

Volumes in cm^3 :

$$\frac{12.5 \times 1}{1} = \frac{10 \times C}{1}$$

$$12.5 = 10 \times C$$

$$C = \frac{12.5}{10.0}$$

$$C = \mathbf{1.25\ mol\ l^{-1}}$$

Volumes in litres :

$$\frac{0.0125 \times 1}{1} = \frac{0.01 \times C}{1}$$

$$0.0125 = 0.01 \times C$$

$$C = \frac{0.0125}{0.01}$$

$$C = \mathbf{1.25\ mol\ l^{-1}}$$

Example 2:

$20cm^3$ sulfuric acid with a concentration of 0.1 mol l^{-1} was required to neutralise $10cm^3$ lithium hydroxide. Calculate the concentration of the lithium hydroxide solution.

$$H_2SO_4(aq) \quad + \quad 2LiOH(aq) \longrightarrow Li_2SO_4(aq) \quad + \quad 2H_2O(l)$$

Working:

Example 3:

If $10cm^3$ of nitric acid is neutralised by 5 cm^3 of potassium hydroxide solution, concentration 0·2 mol l^{-1}, what is the concentration of the acid?

$$HNO_3(aq) \quad + \quad KOH(aq) \longrightarrow KNO_3(aq) \quad + \quad H_2O(l)$$

Working:

Topic Questions

Exercise 1

1. Name a non-metal oxide which will dissolve to form an acidic solution.
2. Describe the ion concentration present in acidic solutions.
3. Name two metal oxides which will dissolve to form an alkaline solution.
4. Name two metal oxides and two metal hydroxides which will not dissolve to form an alkali.
5. Complete the table below

Name of Alkali	Chemical Formula	Ions Present
lithium hydroxide	$LiOH$	Li^{+} and OH^{-}
sodium hydroxide		
	KOH	
	$Ca(OH)_2$	Ca^{2+} and OH^{-}

6. Describe the ion concentration present in alkaline solutions.
7. Which two ions are present in all aqueous solutions?
8. Explain why water is neutral even though it contains hydrogen and hydroxide ions.

Exercise 2

1. The following oxides are soluble in water

A Barium oxide	B Carbon dioxide	C Nitrogen dioxide	D Lithium oxide

   a) Which two substances when dissolved in water produce acidic solutions?

   b) Which two substances when dissolved in water produce alkaline solutions?

   c) What is formed when lithium oxide dissolves in water?

2. Solution A has a pH of 12 while solution B has a pH of 10. Which of two solution contains a greater concentration of OH^{-} ions?

3. Water is a covalent substance which mainly exists as molecules.

   a) Which two ions are present in pure water?

   b) Give the chemical equation for the break up of water molecules to form ions.

   c) Explain why pure water has a pH value of 7.

4. When chlorine dissolves in water (chlorination) the following chemical reaction occurs.

   $Cl_2(g) + H_2O(l) \longrightarrow H^+(aq) + OCl^-(aq) + Cl^-(aq)$

   Explain what happens to the pH of water when it is chlorinated.

5. The boiling point of 5 carbon containing acids are shown below.

Name of acid	Number of carbon atoms	Boiling point ^0C
Methanoic acid	1	102
Ethanoic acid	2	118
Propanoic acid	3	141
Butanoic acid	4	164
Pentanoic acid	5	186

   What is the relationship between the number of carbon atoms and the boiling point?

Exercise 3

1. When an acid and alkali react which two products are formed.
2. Explain what happens to the concentration of hydrogen ions when an acid is neutralised.
3. Explain why water is formed when an acid and alkali react.
4. State the name of the salt formed in the following reactions.

   a) Lithium hydroxide reacts with hydrochloric acid

   b) Sodium hydroxide reacts with nitric acid

   c) Calcium hydroxide reacts with sulfuric acid

   d) Magnesium oxide reacts with nitric acid

5. State the acid and alkali which were used to produce the following salts.

   a) Sodium sulfate

   b) Lithium nitrate

   c) Potassium chloride

6. Write a word equation for the reaction between nitric acid and magnesium hydroxide.

7. Write a balanced chemical equation for the reaction between nitric acid and magnesium hydroxide.

8. Write an ionic equations for the reaction between nitric acid and magnesium hydroxide.

9. Indicate the spectator ions in the above equation (Q 8) by circling them.

Exercise 4

1. What is a base?

2. Which of the following substances will form alkalis when added to water?

i)	barium oxide	ii)	potassium carbonate	iii)	lithium hydroxide
iv)	nickel hydroxide	v)	calcium carbonate	vi)	zinc oxide

3. Which of the following substances are bases and which are salts?

i)	Sodium chloride	ii)	Copper(II) carbonate	iii)	Lithium sulfate
iv)	Magnesium oxide	v)	Zinc(II) nitrate	vi)	Potassium hydroxide

4. Rewrite the following equations, circle the spectator ion and then write the equation omitting the spectator ions

   a) $K^+(aq) + OH^-(aq) + H^+(aq) + NO_3^-(aq) \longrightarrow K^+(aq) + NO_3^-(aq) + H_2O(l)$

   b) $Zn^{2+}O^{2-}(s) + 2H^+(aq) + SO_4^{2-}(aq) \longrightarrow Zn^{2+}(aq) + SO_4^{2-}(aq) + H_2O(l)$

   c) $Cu^{2+}(aq) + SO_4^{2-}(aq) + 2Na^+(aq) + CO_3^{2-}(aq) \longrightarrow Cu^{2+}CO_3^{2-}(s) + 2Na^+(aq) + SO_4^{2-}(aq)$

   d) $2Na^+(aq) + 2I^-(aq) + Pb^{2+}(aq) + 2NO_3^-(aq) \longrightarrow Pb^{2+}(I^-)_2(s) + 2Na^+(aq) + 2NO_3^-(aq)$

   e) $2H^+(aq) + SO_4^{2-}(aq) + Mg^{2+}(aq) + CO_3^{2-}(aq) \longrightarrow Mg^{2+}(aq) + SO_4^{2-}(aq) + H_2O(l) + CO_2(g)$

Exercise 5

1. If 20 cm^3 of hydrochloric acid is neutralised by 40 cm^3 of a solution of sodium hydroxide with concentration 2 mol l^{-1}, what is the concentration of the acid?

$$HCl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + H_2O(l)$$

2. If 100 cm^3 of nitric acid is neutralised by 50 cm^3 of potassium hydroxide solution, concentration 0·2 mol l^{-1}, what is the concentration of the acid?

$$HNO_3(aq) + KOH(aq) \longrightarrow KNO_3(aq) + H_2O(l)$$

3. If 20 cm^3 of sodium hydroxide solution is needed to neutralise 15·6 cm^3 of sulfuric acid, concentration 0.1 mol l^{-1}, what is the concentration of the alkali?

$$H_2SO_4(aq) + 2NaOH(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$$

4. What volume of 0·1 mol l^{-1} hydrochloric acid is required to neutralise 100 cm^3 of a solution of sodium hydroxide with concentration 0·5 mol l^{-1}?

$$HCl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + H_2O(l)$$

5. What volume of 2 mol l^{-1} potassium hydroxide is required to neutralise 50 cm^3 of sulfuric acid with concentration 1 mol l^{-1}?

$$H_2SO_4(aq) + 2KOH(aq) \longrightarrow K_2SO_4(aq) + 2H_2O(l)$$

6. Which of the following substances can be classified as a base?

A Magnesium hydroxide

B Calcium sulfate

C Copper(II) nitrate

D Sodium chloride

7. When a dilute acid reacts with a metal carbonate, hydrogen ions and carbonate ions react to produce

A hydrogen and carbon dioxide

B a salt and carbon dioxide

C a salt and water

D water and carbon dioxide

8. Which of the following is **not** a base?

A Sodium hydroxide

B Calcium carbonate

C Magnesium nitrate

D Copper (II) oxide

9. Which gas is produced when magnesium carbonate reacts with hydrochloric acid?

A Chlorine B Hydrogen C Carbon dioxide D Carbon monoxide

10. When nickel(II) chloride solution is added to sodium carbonate solution an insoluble solid is formed.

A sample of the solid can be separated from the mixture by

A condensation B distillation C evaporation D filtration.

11. When hydrochloric acid with a pH of 3 is diluted with water to give a solution with a pH of 6, the concentration of

A H^+(aq) ions decrease

B OH^-(aq) ions decreases

C H^+(aq) ions and the concentration of OH^-(aq) ions become equal

12. Name the products in the following reactions (some have 3).

a) Calcium hydroxide and nitric acid

b) Magnesium oxide and sulfuric acid

c) Magnesium and nitric acid

d) Copper carbonate and nitric acid

e) Silver oxide and sulfuric acid

f) Aluminium carbonate and hydrochloric acid

Exercise 6

1. A series of elemental oxides were dissolved in water and the pH measured. Complete the following table for the experiment:

Element	**Oxide formed**	**Colour of oxide and indicator**	**Acid/Alkali/Neutral?**
Sulfur			
Calcium			
Nitrogen			
Carbon			
Sodium			

2. What is the definition of an acid?

3. What is the definition of an alkali?

4. During a conductivity experiment of acids, a gas was given off at the negative electrode.

a) What gas could this have been?

b) If the acid was hydrochloric acid, what gas would have been collected at the positive electrode?

c) Complete the following:

Since acids and alkalis both conduct electricity they must contain ___________which are free to move. Water is a ________________________________ because it contains a few ions. Hydrochloric acid is made by _______________________________________ hydrogen chloride gas in ______________.

5. Why is water neutral?

6. pH is dependant on the concentration of hydrogen ions in the solution.

   a) What happens to the concentration of hydroxide ions as pH 14 sodium hydroxide is diluted?

   b) What happens to the pH as an acid is diluted?

Exercise 7

1. Complete the following word equations:

   a) hydrochloric acid + lithium carbonate

   b) sulfuric acid + sodium hydroxide

2. Complete and balance the following chemical equations:

   a) $K_2O(aq)$ + $HNO_3(aq)$

   b) $Ca(OH)_2(aq)$ + $H_3PO_4(aq)$

3. Write a balanced ionic equation for the following neutralisation reactions:

   a) nitric acid and sodium hydroxide

   b) sulfuric acid and lithium hydroxide

   c) hydrochloric acid and potassium hydroxide

4. Calculate the volume of hydrochloric acid (0.1 mol l^{-1}) required to neutralise 50 cm^3 of 0.2 mol l^{-1} potassium hydroxide solution.

   $HCl + KOH \longrightarrow KCl + H_2O$

5. Calculate the concentration of sulphuric acid if 17.3 cm^3 neutralises 25 cm^3 of 0.5 mol l^{-1} sodium hydroxide.

   $H_2SO_4 + 2NaOH \longrightarrow Na_2SO_4 + 2H_2O$

6. In a titration 30 cm^3 of nitric acid neutralised 20 cm^3 of a 0.2 mol l^{-1} sodium hydroxide solution.

   Calculate the concentration of the nitric acid.

   $HNO_3 + NaOH \longrightarrow NaNO_3 + H_2O$