Polyatomic Formulae

Learning Outcomes:

1) Recall the formulae for some common polyatomic ions, eg the sulfate ion is SO_4^{2-}
2) Deduce the formula of ionic substances containing polyatomic ions

If a compound contains one polyatomic ion the formula is simple. For example Li^+ joins with OH^- to form LiOH. If there is more than one of the polyatomic ion, it goes in brackets with the number afterwards as a subscript. For example Mg^{2+} joins with $2OH^-$ to make $Mg(OH)_2$.

Polyatomic ion	Charge	Formulae
hydroxide	-1	OH^-
sulfate	-2	SO_4^{2-}
carbonate	-2	CO_3^{2-}
nitrate	-1	NO_3^-
ammonium	+1	NH_4^+

As you know you can use the periodic table to work out the charges on the ions from group 1, 2, 3, 5, 6 & 7.
There are however 7 monoatomic ions that you came across in the Ions topic in which you cannot use the periodic to work out their charges.

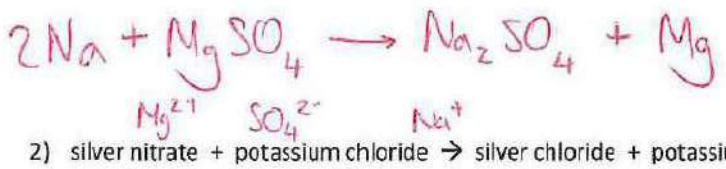
Ion	Formula
hydrogen	H^+
silver	Ag^+
zinc	Zn^{2+}
copper (II)	Cu^{2+}
lead (II)	Pb^{2+}
iron(II)	Fe^{2+}
iron(III)	Fe^{3+}

Ionic compound	Ions in the compound	Formula
Sodium hydroxide	Na^{1+} OH^{1-}	NaOH
Calcium hydroxide	Ca^{2+} OH^{1-} OH^{1-}	$Ca(OH)_2$
Magnesium sulfate	Mg^{2+} SO_4^{2-}	$MgSO_4$
Potassium nitrate	K^+ NO_3^-	KNO_3
Calcium hydroxide	Ca^{2+} OH^- OH^-	$Ca(OH)_2$
Aluminium nitrate	Al^{3+} NO_3^- NO_3^- NO_3^-	$Al(NO_3)_3$
Ammonium chloride	NH_4^+ Cl^-	NH_4Cl
Lithium sulfate	Li^+ Li^+ SO_4^{2-}	Li_2SO_4
Magnesium carbonate	Mg^{2+} CO_3^{2-}	$MgCO_3$
Aluminium sulfate	Al^{3+} Al^{3+} SO_4^{2-} SO_4^{2-} SO_4^{2-}	$Al_2(SO_4)_3$
ammonium oxide	NH_4^+ NH_4^+ O^{2-}	$(NH_4)_2O$
Lithium carbonate	Li^+ Li^+ CO_3^{2-}	Li_2CO_3
Potassium hydroxide	K^+ OH^-	KOH
Lithium nitrite NO_2^-	Li^+ NO_2^-	$LiNO_2$
Magnesium nitrate	Mg^{2+} NO_3^- NO_3^-	$Mg(NO_3)_2$
Beryllium sulfate	Be^{2+} SO_4^{2-}	$BeSO_4$

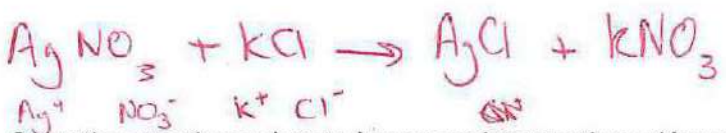
Ionic compound	Ions in the compound	formula
Rubidium sulfate	Rb^+ SO_4^{2-} Rb^+	Rb_2SO_4
ammonium nitrate	NH_4^+ NO_3^-	NH_4NO_3
Caesium nitrate	Cs^+ NO_3^-	$CsNO_3$
ammonium carbonate	NH_4^+ CO_3^{2-} NH_4^+	$(NH_4)_2CO_3$
Gallium hydroxide	Ga^{3+} OH^- OH^- OH^-	$Ga(OH)_3$
Zinc sulfate	Zn^{2+} SO_4^{2-}	$ZnSO_4$
Lead(II) nitrate	Pb^{2+} NO_3^- NO_3^-	$Pb(NO_3)_2$
Silver hydroxide	Ag^+ OH^-	$AgOH$
Zinc nitrate	Zn^{2+} NO_3^- NO_3^-	$Zn(NO_3)_2$
Hydrogen sulfate	H^+ SO_4^{2-} H^+	H_2SO_4
Iron(II) hydroxide	Fe^{2+} OH^- OH^-	$Fe(OH)_2$
Iron(III) hydroxide	Fe^{3+} OH^- OH^- OH^-	$Fe(OH)_3$
Copper(II) sulfate	Cu^{2+} SO_4^{2-}	$CuSO_4$
Copper(II) nitrate	Cu^{2+} NO_3^- NO_3^-	$Cu(NO_3)_2$
Iron(II) nitrate	Fe^{2+} NO_3^- NO_3^-	$Fe(NO_3)_2$
Iron(III) carbonate	Fe^{3+} Fe^{3+} CO_3^{2-} CO_3^{2-} CO_3^{2-}	$Fe_2(CO_3)_3$

Task: Write the chemical equations for the following reactions. You will need to work out the formulae of the substances and then balance the equation.

1) sodium + magnesium sulfate → sodium sulfate + magnesium

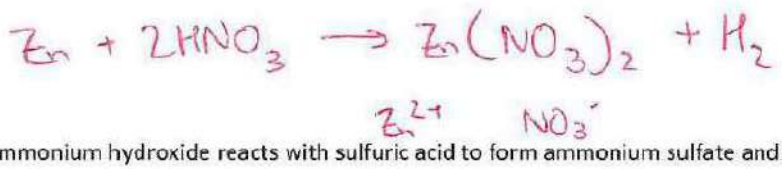


2) silver nitrate + potassium chloride → silver chloride + potassium nitrate

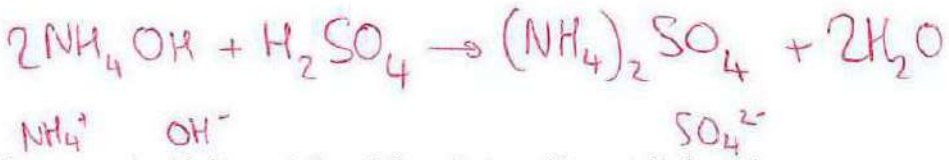


3) On heating, strontium carbonate decomposes into strontium oxide and carbon dioxide

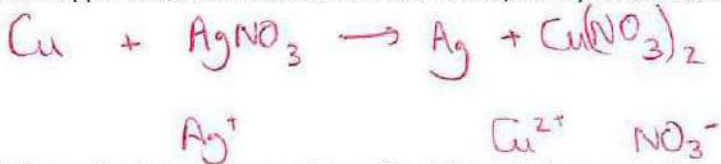
4) A solution of zinc nitrate is formed when zinc reacts with nitric acid. Hydrogen gas is also given off.



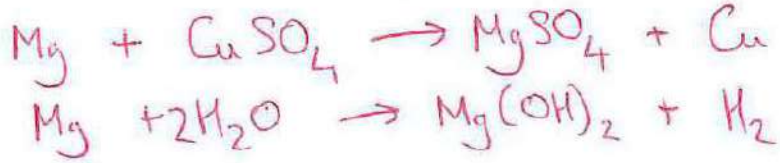
5) Ammonium hydroxide reacts with sulfuric acid to form ammonium sulfate and water



6) When copper is added to a solution of silver nitrate, a shiny metal is formed



7) Challenge. A solution of magnesium sulfate is formed when magnesium reacts with copper sulfate. Hydrogen gas is also given off. (Note: this is a tricky one – there are 2 reactions going on)



Indicators & Neutralisation

Learning Outcomes:

1) Describe the use of the indicators to distinguish between acidic and alkaline solutions
2) Define acids as sources of hydrogen ions, H^+, and alkalis as sources of hydroxide ions, OH^-

Task: How many different acids and alkalis can you remember?

Acid		Alkali	
Name	**Formula**	**Name**	**Formula**
hydrochloric acid	HCl	sodium hydroxide	$NaOH$
sulfuric acid	H_2SO_4	ammonium hydroxide	NH_4OH
nitric acid	HNO_3		

Acids in solution are a source of hydrogen ions (H^+)

Alkalis in solution are a source of hydroxide ions (OH^-)

Complete this key acid neutralisation reaction:

acid + **alkali** → salt + water

Practical **acid + alkali neutralisation**

Acids can be **neutralised** by alkalis to form salt and water:

acid + alkali → salt + water

All simple acids contain a hydrogen ion. When that hydrogen ion is replaced by a metal ion, the compound formed called a **salt.**

Procedure

1. *Pipette 2cm^3 of HCl to a boiling tube*
2. *Add a couple of drops of universal indicator*
3. *Slowly pipette NaOH into the test tube until the colour changes to green*
4. *If you overshoot the mark, pipette some more HCl into the boiling tube*

Task: Write the word and chemical equation for the reaction between hydrochloric acid and sodium hydroxide

hydrochloric acid + sodium hydroxide → sodium chloride + water

$HCl + NaOH \longrightarrow NaCl + H_2O$

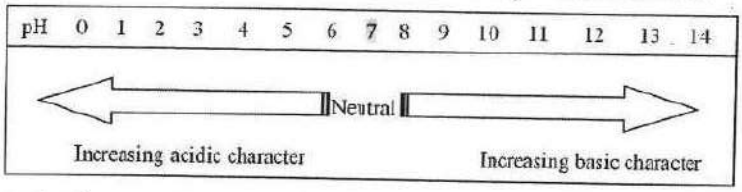
H^+ OH^-

TASK: Label your chemical equation above to show what happens during neutralisation to the hydrogen ion(H^+) in th and the hydroxide ion (OH^-) ion in the alkali.

This is a simple definition of neutralisation. A better definition of neutralisation is the reaction between an acid and base to produce water and salt only. An alkali is a soluble base. To see this, we need a more detailed definition of a and bases.

pH & indicators

The **pH scale** ranges from about 0 to 14, and tells you how acidic or how alkaline a solution is.



An **indicator** is a substance that has more than one colour form depending on the pH.

Demo / Practical **Indicators**

There are several other indicators that we use in chemistry. Each indicator has a different colour change.

Using hydrochloric acid & sodium hydroxide determine the colour change of these indicators.

Procedure

1. *Pipette 2cm³ of HCl to a test tube*
2. *Add a couple of drops of indicator and record the colour change*
3. *Slowly pipette NaOH into the test tube until there is a colour change. Record this change*
4. *Repeat the procedure with a different indicator*

Indicator	Colour in acidic solution	Colour in alkaline solution
Litmus	red	blue
Methyl orange	red	yellow
Phenolphthalein	colourless	pink
Universal indicator	red / orange	blue / purple

What is different about universal indicator compared to the others?

.....shows how acidic / alkaline a substance is.....

Is this an advantage or a disadvantage? Explain why? .....

.....

.....

The pH scale, from 0–14, can be used to classify solutions as strongly acidic (0–3), weakly acidic (4–6), neutral (7), weakl alkaline (8–10) and strongly alkaline (11–14)

Demonstration of acids and alkalis of differing strength and the colour of Universal Indicator

Universal indicator is a mixture of different dyes which change colour in a gradual way over a range of pH:

Example of substance	Colour of universal indicator	Strength acid/alkali	pH
Hydrochloric acid	red	strong acid	1
Ethanoic acid solution	orange	weak acid	4
Magnesium sulfate solution	yellow	weak acid	6
Distilled Water	green	neutral	7
Sodium chloride solution	green	neutral	7
Magnesium hydroxide	blue	weak alkali	10
Sodium hydroxide	purple	strong alkali	13

Questions on acids, alkalis and indicators

1) What colour is phenolphthalein when sodium hydroxide is added? pink

2) What colour is methyl orange when nitric acid is added? red

3) What colour is litmus when phosphoric acid is added? red

4) What colour is methyl orange when a sodium hydroxide is added? yellow

5) What colour is phenolphthalein when H_2SO_4 is added? colourless

6) Which common indicator solution goes yellow when KOH is added? methyl orange

7) What colour is litmus when $Ca(OH)_2$ is added? blue

8) What colour is phenolphthalein in distilled water? colourless

Notes: colourless at ≤ 7, pink > 7

9) What colour is universal indicator when added to copper oxide and water? blue

Notes: copper oxide + water is basic

What "type" of compound is this?

For each of the compounds below, say whether it is:

acid or **alkali** or **base** or **metal** or **carbonate** or **salt**

Don't worry, you will learn the proper definitions of these words in the next few lessons.

Compound	Type		Compound	Type
Aluminium nitrate	Salt		Lithium sulfate	Salt
Aluminium sulfate	Salt		Magnesium	Metal
ammonium carbonate	Carbonate		Magnesium carbonate	Carbonate
Ammonium chloride	Salt		magnesium hydroxide	Alkali
ammonium hydroxide	Alkali		Magnesium nitrate	Salt
Beryllium sulfate	Salt		magnesium oxide	Base
Caesium nitrate	Salt		nitric acid	Acid
Calcium	Metal		phosphoric acid	Acid
Calcium hydroxide	Alkali		Potassium	Metal
citric acid	Acid		Potassium carbonate	Carbonate
Copper oxide	Base		potassium hydroxide	Alkali
Copper(II) nitrate	Base		Potassium nitrate	Salt
Copper(II) sulfate	Salt		Sodium	Metal
Gold	Metal		sodium hydroxide	Alkali
hydrochloric acid	Acid		sulfuric acid	Acid
Iron	Metal		Zinc carbonate	Carbonate
Iron oxide	Base		Zinc nitrate	Salt
Iron(II) nitrate	Salt		Zinc oxide	Base
Lead oxide	Base		Zinc sulfate	Salt
Lithium carbonate	Carbonate			

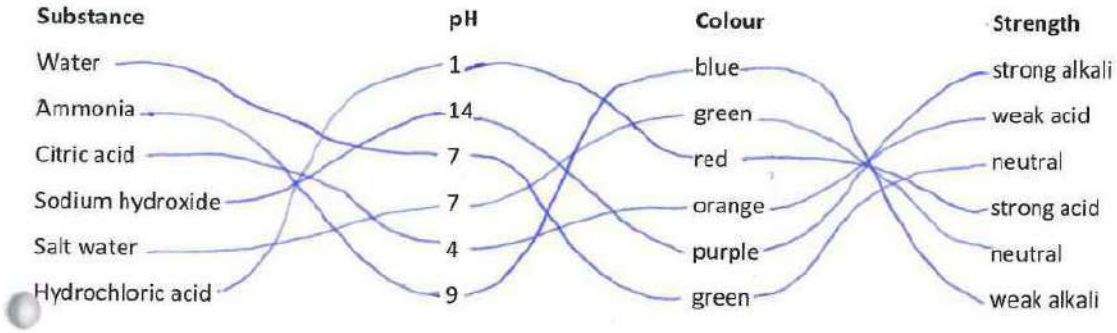
Now review your answers. Could some compounds be classified in more than one type? If so, which ones?

Acid + Base

Learning Outcomes:

1) Recall the definition of an acid, alkali, base and salt
2) Describe the neutralisation reaction between an acid and alkali and an acid and base
3) Write the word equations for neutralisation reactions

Task: Match up the substance with its correct pH value, colour with universal indicator and description



Key definitions:

Acids are described as having a pH of less than 7.

Alkalis are described as having a pH of more than 7.

A **Base** is a substance which can neutralise an acid, forming salt + water only.

A **Salt** is what is produced when a hydrogen ion is replaced by a metal ion.

So what do an alkali and a base have in common?

- both neutralise acid
- produce salt + water

What is the difference between an alkali and a base?

- alkali is a soluble base
- bases are not soluble in water

Naming salts

Different salts can be made by neutralising different acids and alkalis:

Hydrochloric acid reacts to give salts called <u>chlorides</u>.

Sulfuric acid reacts to give salts called <u>sulfates</u>.

Nitric acid reacts to give salts called <u>nitrates</u>.

For example

calcium hydroxide + **sulfuric** acid → *calcium* **sulfate** + water

ammonium hydroxide + **nitric** acid → *ammonium* **nitrate** + water

Task: Complete the following word equations

a) sodium hydroxide + nitric acid → sodium nitrate + water

b) potassium hydroxide + sulfuric acid → potassium sulfate + water

c) ammonium hydroxide + hydrochloric acid → ammonium chloride + water

d) calcium hydroxide + nitric acid → calcium nitrate + water

e) potassium hydroxide + phosphoric acid → potassium phosphate + water

f) magnesium hydroxide + citric acid → magnesium citrate + water

1. Complete the following word equations, setting them out on two lines:

(a) nitric acid + potassium hydroxide → potassium nitrate + water

(b) hydrochloric acid + magnesium hydroxide → magnesium chloride + water

(c) sulfuric + acid sodium hydroxide → sodium sulfate + water

(d) nitric acid + copper(II) oxide → copper (II) nitrate + water

(e) hydrochloric acid + zinc oxide → zinc chloride + water

(f) sulfuric + acid calcium oxide → calcium sulfate + water

(g) phosphoric acid + iron(II) hydroxide → iron (II) phosphate + water

(h) citric acid + ammonium hydroxide → ammonium citrate + water

(i) hydrochloric acid + rubidium hydroxide → rubidium chloride + water

(j) sulfuric + acid copper(II) oxide → copper (II) sulfate + water

(k) nitric acid + aluminium oxide → aluminium nitrate + water

(l) hydrochloric acid + ammonium hydroxide → ammonium chloride + water

Carbonate + Acid

Learning Outcomes:

1) Describe the reactions between metal carbonates and acids
2) Write the word equations for these reactions

Practical **Carbonates and Acids**

Δ Safety *Risk of acid in eyes.*

- Put half a spatula of solid in a test tube and **place in a test tube rack**
- Add a small amount of hydrochloric acid (HCl) and test any gases that are produced.
- Carefully record your observations.

Metal Carbonate	**Observation**	**Gases produced**
Calcium carbonate $CaCO_3$	• solid disappears / becomes smaller • gas bubbles produced	carbon dioxide
Copper carbonate $CuCO_3$	• solid disappears / becomes smaller • bubbles	carbon dioxide
Sodium carbonate Na_2CO_3	• solid disappears / becomes smaller • bubbles	carbon dioxide
Sodium hydrogen carbonate $NaHCO_3$	• solid becomes smaller • bubbles of gas	carbon dioxide

Write the word equations for the reactions carried out today.

① calcium carbonate + hydrochloric acid → calcium chloride + water + carbon dioxide

② copper carbonate + hydrochloric acid → copper chloride + water + carbon dioxide

③ sodium carbonate + hydrochloric acid → sodium chloride + water + carbon dioxide

④ sodium hydrogen carbonate + hydrochloric acid → sodium chloride + water + carbon dioxide

Metal + Acid

Learning Outcomes:

1) Describe the reactions between metals and acids
2) Write the word equations for these reactions

Practical **Metals with acid** 

Δ Care *Remember how to pour from reagent bottle.*

Add about 3 cm^3 dilute hydrochloric acid to metal sample (Mg, Zn, Fe, Pb, Cu). Warm if necessary. Collect any gas evolved by holding a second test-tube on top of the first and then test with lighted splint. Dispose of products by pou into residues container, not down sink.

Metal	Appearance of reaction	Test with lit splint (Hydrogen present or
Mg	• Mg disappears • bubbles	✓ squeaky pop
Zn	• Zn disappears • bubbles	✓ "
Fe	• Fe disappears • bubbles	✓ "
Pb	• Pb disappears • bubbles	✓ "
Cu	• Cu disappears • bubbles	✓ "
Ca (demo)	• Ca disappears • bubbles	✓ "

Write the word equations for the reactions carried out today.

① magnesium + hydrochloric acid → magnesium chloride + hydrogen

② zinc + hydrochloric acid → zinc chloride + hydrogen

③ iron + hydrochloric acid → iron chloride + hydrogen

④ lead + hydrochloric acid → lead chloride + hydrogen

⑤ copper + hydrochloric acid → copper chloride + hydrogen

⑥ calcium + hydrochloric acid → calcium chloride + hydrogen

Thermal decomposition of metal carbonates

Learning Outcomes:

1) Describe the thermal decomposition of metal carbonates
2) Write the word equations for these reactions

When heated, metal carbonates decompose to form a metal oxide and carbon dioxide:

carbonate → **metal oxide** + **carbon dioxide**

For example:

copper carbonate → copper oxide + carbon dioxide

$CuCO_3 \rightarrow CuO + CO_2$

Try some more word equations for thermal decomposition of metal carbonates:

magnesium carbonate → magnesium oxide + carbon dioxide

$MgCO_3 \rightarrow MgO + CO_2$

calcium carbonate → calcium oxide + carbon dioxide

$CaCO_3 \rightarrow CaO + CO_2$

sodium carbonate → sodium oxide + carbon dioxide

$Na_2CO_3 \rightarrow Na_2O + CO_2$

lithium carbonate → lithium oxide + carbon dioxide

$Li_2CO_3 \rightarrow Li_2O + CO_2$

potassium carbonate → potassium oxide + carbon dioxide

$K_2CO_3 \rightarrow K_2O + CO_2$

Task: now go back and write the chemical equation for each of the above thermal decomposition reactions.

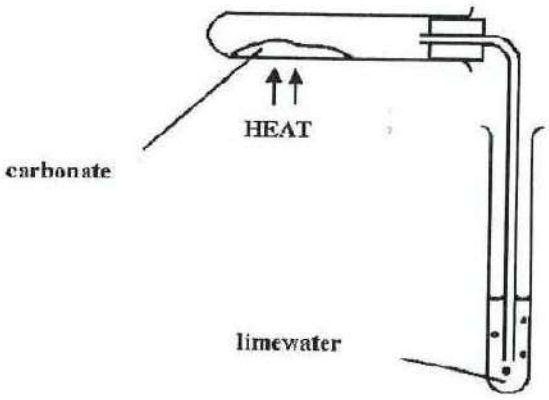
Practical **Thermal decomposition of metal carbonates**

Δ Safety *Test tube gets very hot – take care not to touch!.*

To prevent suck back, remove lime water before heat is stopped,

Risk of alkali in eyes or on hands.

We will heat a range of metal carbonates.
For each we will measure the mass before and after.
We will also test any gas produced to see if it is carbon dioxide.



Results

Metal carbonate	Formula	Mass before	Mass after	Mass change	Observations of limewater
Copper carbonate	$CuCO_3$				goes cloudy
Potassium carbonate	K_2CO_3				goes cloudy
Zinc carbonate	$ZnCO_3$				turns cloudy
					turns cloudy

How can we make sure the reactions had finished?

• Repeat heating until mass does not change

" repeat until constant mass "

Why did the solid change mass, and what does the change in mass represent?

- loss of CO_2 as a gas

Write the word equations and the chemical equations for the reactions that happened.

(1) copper carbonate → copper oxide + carbon dioxide

$CuCO_3 \rightarrow CuO + CO_2$

(2) potassium carbonate → potassium oxide + carbon dioxide

$K_2CO_3 \rightarrow K_2O + CO_2$

(3) zinc carbonate → zinc oxide + carbon dioxide

$ZnCO_3 \rightarrow ZnO + CO_2$

Extension: For each of the reactions, was the change in mass what we could have expected?

How can we calculate what the change in mass *should* have been in a perfect experiment?

Write the word and chemical equations for the reactions of the following elements and oxygen.

Example
Magnesium reacts with oxygen to give magnesium oxide

1) Write the correct formulae (Oxygen gas is always O_2). Remember to use the charges on the ions.
2) Balance
   - magnesium + oxygen → magnesium oxide
   - **2Mg + O_2 → 2MgO**

1. Copper reacts with oxygen to give copper(II) oxide → Cu^{2+} O^{2-}

$$2Cu_{(s)} + O_{2(g)} \rightarrow 2CuO_{(s)}$$

2. Sulfur reacts with oxygen to give sulfur dioxide (SO_2)

$$S_{8(s)} + 8O_{2(g)} \rightarrow 8SO_{2(g)}$$

3. Carbon reacts with oxygen to give carbon dioxide(CO_2)

$$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$$

4. Calcium reacts with oxygen to give calcium oxide

$$2Ca_{(s)} + O_{2(g)} \rightarrow 2CaO_{(s)}$$

5. Aluminium reacts with oxygen to give aluminium oxide → Al^{3+} O^{2-}

$$4Al_{(s)} + 3O_{2(g)} \rightarrow 2Al_2O_{3(s)}$$

Now go back and add state symbols to every formula.

Chemical equations

You have learnt the following key reactions:

Alkali	+	**acid**	→	**salt**	+	**water**		
Base	+	**acid**	→	**salt**	+	**water**		
Carbonate	+	**acid**	→	**salt**	+	**water**	+	**carbon dioxide**
Metal	+	**acid**	→	**salt**	+	**hydrogen**		
metal	+	**oxygen**	→	**metal oxide**				**(NB: oxygen gas is always O_2)**
carbonate			→	**metal oxide**	+	**carbon dioxide**		**(thermal decomposition)**

Task write chemical equations for the following reactions.

Remember to do the following steps:

- Identify the key reaction in order to help you work out the products
- Work out the correct formulae for the reactants and products
- Balance the whole equation

The first one has been done for you.

(a) hydrochloric acid + sodium hydroxide → sodium chloride + water

Acid + Alkali → Salt + Water

HCl + NaOH → NaCl + H_2O Balanced = Yes.

(b) hydrochloric acid + magnesium → magnesium chloride + hydrogen

MASH

$2HCl + Mg \rightarrow MgCl_2 + H_2$

(c) sulfuric acid + sodium oxide → sodium sulfate + water

BANS

$H_2SO_4 + Na_2O \rightarrow Na_2SO_4 + H_2O$

(d) nitric acid + copper(II) carbonate → copper (II) nitrate + carbon dioxide + water

CANS

COD

$2HNO_3 + CuCO_3 \rightarrow Cu(NO_3)_2 + CO_2 + H_2O$

(e) Zinc + oxygen → zinc oxide

$2Zn + O_2 \rightarrow 2ZnO$

(f) Magnesium carbonate $\xrightarrow{\text{(heat)}}$ magnesium oxide + carbon dioxide

$MgCO_3 \rightarrow MgO + CO_2$

MASH (g) hydrochloric acid + zinc → zinc chloride + hydrogen

$2HCl + Zn \rightarrow ZnCl_2 + H_2$

CAWS (h) sulfuric acid + calcium carbonate → calcium sulfate + carbon dioxide + water

COD

$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + CO_2 + H_2O$

AAWS (i) Nitric acid + iron(II) hydroxide → iron (II) nitrate + water

$2HNO_3 + Fe(OH)_2 \rightarrow Fe(NO_3)_2 + 2H_2O$

4 : H : 2
2 : O : 1

AAWS (j) sulfuric acid + ammonium hydroxide → ammonium sulfate + water

$H_2SO_4 + 2NH_4OH \rightarrow (NH_4)_2SO_4 + 2H_2O$

4 : H : 2
2 : O : 1

MASH (k) hydrochloric acid + rubidium → rubidium chloride + hydrogen

$2HCl + 2Rb \rightarrow 2RbCl + H_2$

(l) sulfuric acid + copper(II) oxide → copper (II) sulfate + water

BAWS

$H_2SO_4 + CuO \rightarrow CuSO_4 + H_2O$

(m) nitric acid + aluminium → aluminium nitrate + hydrogen

MASH

$3HNO_3 + Al \rightarrow Al(NO_3)_3 + 1\frac{1}{2}H_2$

(n) hydrochloric acid + ammonium carbonate → ammonium chloride + carbon dioxide + water

CAWS CoD

$2HCl + (NH_4)_2CO_3 \rightarrow 2NH_4Cl + CO_2 + H_2O$

(o) Hydrochloric acid reacts with a piece of aluminium producing a colourless solution and a gas.

MASH

$3HCl + Al \rightarrow AlCl_3 + 1\frac{1}{2}H_2$

hydrochloric acid + aluminium → aluminium chloride + hydrogen

(p) Fizzing is observed when potassium carbonate is placed into sulfuric acid

CAWS CoD

potassium carbonate + sulfuric acid → potassium sulfate + carbon dioxide + water

$K_2CO_3 + H_2SO_4 \rightarrow K_2SO_4 + CO_2 + H_2O$

(q) Ammonium hydroxide is neutralised by adding nitric acid

AAWS

ammonium hydroxide + nitric acid → ammonium nitrate + water

$NH_4OH + HNO_3 \rightarrow NH_4NO_3 + H_2O$

(r) On heating zinc carbonate produces a gas that is collected and turns limewater cloudy

zinc carbonate → zinc oxide + carbon dioxide

$ZnCO_3 \rightarrow ZnO + CO_2$

(s) A black powder of copper oxide is dissolved into warm sulfuric acid. The solution turns blue.

BAWS

copper oxide + sulfuric acid → copper sulfate + water

$CuO + H_2SO_4 \rightarrow CuSO_4 + H_2O$

Complete the following cycle using chemical and common names: