Chemistry Department

Year 12 Introductory Work

We would like you to work through this document as well as you can. We acknowledge that you all come into the Sixth Form with different knowledge and skills and have therefore separated all the exercises into three categories:

MUST	You must work through and complete all of these exercises
SHOULD	Most students will complete all of these exercises and, at the very least, give them a good attempt
COULD	Some students will attempt these questions if they feel secure with the previous sections

Task

1. Must
2. Should
3. Could
4. Must
5. Should
6. Could
7. Must
8. Could
9. Must
10. Questions 1-5 = Must; Questions 6-10 = Should; Questions 11-16 = Could
11. X
12. Questions 1-2 = Must; Questions 3-5 = Should; Questions 6-7 = Could
13. Must
14. X
15. Could
16. X
17. X
18. Must

Challenge 1 & Calculation Allsorts = Could

The charges on common ions

Positive ions (cations)			Negative ions (anions)		
Charge	***Cation***	***Symbol***	***Charge***	***Anion***	***Symbol***
1+	Sodium	Na^+	1-	Chloride	Cl^-
	Potassium	K^+		Bromide	Br^-
	Silver	Ag^+		Iodide	I^-
	Copper (I)	Cu^+		Hydroxide	OH^-
	Hydrogen	H^+		Nitrate	NO_3^-
	Ammonium	NH_4^+		Nitrite	NO_2^-
				Cyanide	CN^-
				Hydride	H^-
				Hydrogen carbonate	HCO_3^-
2+	Magnesium	Mg^{2+}	2-	Oxide	O^{2-}
	Calcium	Ca^{2+}		Sulphide	S^{2-}
	Zinc	Zn^{2+}		Sulphate or Sulphate (VI)	SO_4^{2-}
	Copper (II)	Cu^{2+}		Sulphite or Sulphate (IV)	SO_3^{2-}
	Iron (II)	Fe^{2+}		Carbonate	CO_3^{2-}
	Lead (II)	Pb^{2+}			
3+	Aluminium	Al^{3+}	3-	Nitride	N^{3-}
	Iron (III)	Fe^{3+}		Phosphate	PO_4^{3-}

Note

- Metal ions are always positive
- Non-metal ions are negative except hydrogen, H^+, and ammonium, NH_4^+
- Some metals can form more than one ion – this is characteristic of transition metals such as copper and iron
- Some non-metal ions are molecular ions containing more than one kind of atom

1 - FORMULAS

If you are serious about doing A level Chemistry, you **MUST** be able to write a formula without a second thought. It is the single most essential skill for an A level chemist.

You have to know and be able to use the information on this page – you should not be looking it up. There is no data sheet with ion charges at A level.

If you can't write a formula in an instant, **DROP CHEMISTRY NOW** and choose something else.

Elements

Monatomic	Simple molecular	Ionic	Metallic	Giant covalent
helium neon argon krypton xenon radon	hydrogen nitrogen oxygen fluorine chlorine bromine iodine phosphorus sulfur	There are no ionic elements!!	The formula is just the symbol, e.g. magnesium iron sodium nickel	The formula is just the symbol diamond graphite silicon

Compounds

Monatomic	Simple molecular	Ionic	Metallic	Giant covalent
There are no monatomic compounds!!	Some common molecular compounds: carbon dioxide carbon monoxide nitrogen monoxide nitrogen dioxide sulfur dioxide sulfur trioxide ammonia methane hydrogen sulfide	These have to be worked out using Ion charges – you have to know these at AS/A level! LEARN them ASAP. Note these acids: hydrochloric acid sulfuric acid nitric acid phosphoric acid	There are no metallic compounds!!	silicon dioxide

Positive ions		Negative Ions	
Group 1 ions: lithium sodium potassium Group 2 Ions: magnesium calcium barium	Group 3 ions: aluminium Other common ions silver zinc ammonium hydrogen	Group 7 ions: fluoride chloride bromide iodide Group 6 Ions: oxide sulfide	Other common ions nitrate sulfate carbonate hydrogencarbonate hydroxide hydride phosphate

TASK 1 – WRITING FORMULAS OF IONIC COMPOUNDS

1) silver bromide .....
2) sodium carbonate .....
3) potassium oxide .....
4) iron (III) oxide .....
5) chromium (III) chloride .....
6) calcium hydroxide .....
7) aluminium nitrate .....
8) sodium sulfate .....
9) lead (II) oxide .....
10) sodium phosphate .....
11) zinc hydrogencarbonate .....
12) ammonium sulphate .....
13) gallium hydroxide .....
14) strontium selenide .....
15) radium sulfate .....
16) sodium nitride .....

TASK 2 – WRITING FORMULAS 1

1) lead (IV) oxide .....
2) copper .....
3) sodium .....
4) ammonium chloride .....
5) ammonia .....
6) sulfur .....
7) sulfuric acid .....
8) neon .....
9) silica .....
10) silicon .....
11) barium hydroxide .....
12) tin (IV) chloride .....
13) silver nitrate .....
14) iodine .....
15) nickel .....
16) hydrogen sulfide .....
17) titanium (IV) oxide .....
18) lead .....
19) strontium sulfate .....
20) lithium .....

TASK 3 – WRITING FORMULAS 2

1) silver carbonate .....
2) gold .....
3) platinum (II) fluoride .....
4) nitric acid .....
5) ammonia .....
6) silicon (IV) hydride .....
7) phosphorus .....
8) diamond .....
9) vanadium (V) oxide .....
10) cobalt (II) hydroxide .....
11) barium hydroxide .....
12) ammonia .....
13) hydrochloric acid .....
14) fluorine .....
15) silicon .....
16) calcium phosphate .....
17) rubidium .....
18) germanium (IV) oxide .....
19) magnesium astatide .....
20) nitrogen oxide .....

2 - EQUATIONS

From an early age you should have been able to balance chemical equations. However, at A level, you will often need to:

- work out the formulas yourselves
- work out what is made (so you need to know some basic general equations)
- for reactions involving ions in solution, write ionic equations

Some general reactions you should know:

General Reaction	Examples
substance + oxygen → oxides	$2\ Mg + O_2 \rightarrow 2\ MgO$ $2\ H_2S + 3\ O_2 \rightarrow 2\ H_2O + 2\ SO_2$ $C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$
metal + water → metal hydroxide + hydrogen	$2\ Na + 2\ H_2O \rightarrow 2\ NaOH + H_2$
metal + acid → salt + hydrogen	$Mg + 2\ HCl \rightarrow MgCl_2 + H_2$
oxide + acid → salt + water	$MgO + 2\ HNO_3 \rightarrow Mg(NO_3)_2 + H_2O$
hydroxide + acid → salt + water	$2\ NaOH + H_2SO_4 \rightarrow Na_2SO_4 + H_2O$
carbonate + acid → salt + water + carbon dioxide	$CuCO_3 + 2\ HCl \rightarrow CuCl_2 + H_2O + CO_2$
hydrogencarbonate + acid → salt + water + carbon dioxide	$KHCO_3 + HCl \rightarrow KCl + H_2O + CO_2$
ammonia + acid → ammonium salt	$NH_3 + HCl \rightarrow NH_4Cl$
metal carbonate → metal oxide + carbon dioxide (on heating)	$CaCO_3 \rightarrow CaO + CO_2$

TASK 4 – WRITING BALANCED EQUATIONS

1) Balance the following equations.

   a) $Mg + HNO_3 \rightarrow Mg(NO_3)_2 + H_2$

   b) $CuCl_2 + NaOH \rightarrow Cu(OH)_2 + NaCl$

   c) $SO_2 + O_2 \rightarrow SO_3$

   d) $C_4H_{10} + O_2 \rightarrow CO_2 + H_2O$

2) Give balanced equations for the following reactions.

   a) sodium + oxygen → sodium oxide

   b) aluminium + chlorine → aluminium chloride

   c) calcium + hydrochloric acid → calcium chloride + hydrogen

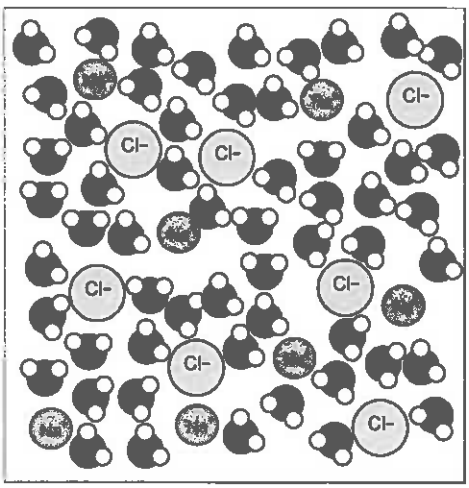
   d) ammonia + sulphuric acid → ammonium sulphate

TASK 5 – WRITING BALANCED EQUATIONS 2

Write balance equations for the following reactions:

1) burning aluminium
2) burning hexane (C_6H_{14})
3) burning ethanethiol (CH_3CH_2SH)
4) reaction of lithium with water
5) reaction of calcium carbonate with nitric acid
6) thermal decomposition of lithium carbonate
7) reaction of ammonia with nitric acid
8) reaction of potassium oxide with water
9) reaction of calcium hydroxide with hydrochloric acid
10) reaction of zinc with phosphoric acid
11) reaction of sodium hydrogencarbonate with sulfuric acid
12) reaction of potassium hydroxide with sulfuric acid

Ionic equations



When an ionic substance dissolves in water, the positive and negative ions separate and become hydrated (they interact with water molecules rather than each other). For example, a solution of sodium chloride could also be described as a mixture of hydrated sodium ions and hydrated chloride ions in water.

In reactions involving ionic compounds dissolved in water, some of the ions may not be involved in the reaction. These are called ***spectator ions***. For such reactions, we can write an ***ionic equation*** that only shows the species that are involved in the reaction.

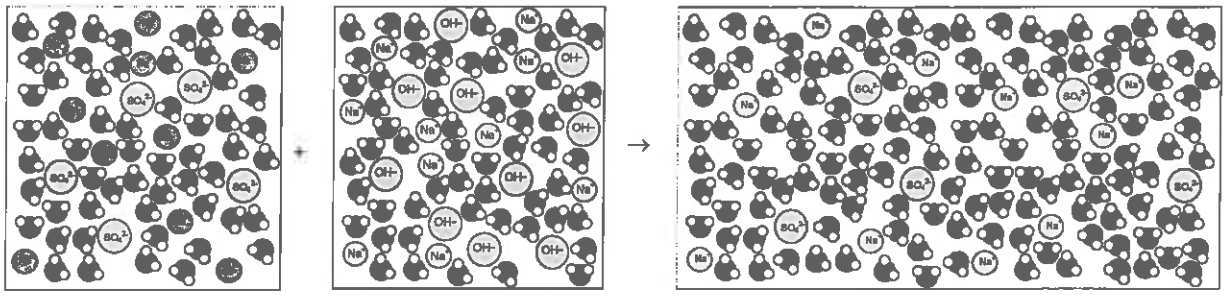
Simple examples are equations for which ionic equations can be written include:

Reactions of acids:

Common ionic equations are:	acid + hydroxide	$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$
	acid + carbonate	$2\ H^+(aq) + CO_3^{2-}(aq) \rightarrow H_2O(l) + CO_2(g)$
	acid + hydrogencarbonate	$H^+(aq) + HCO_3^-(aq) \rightarrow H_2O(l) + CO_2(g)$
	acid + ammonia	$H^+(aq) + NH_3(aq) \rightarrow NH_4^+(aq)$

We can even use these ionic equations to work out the ratio in which acids react without writing any equation.

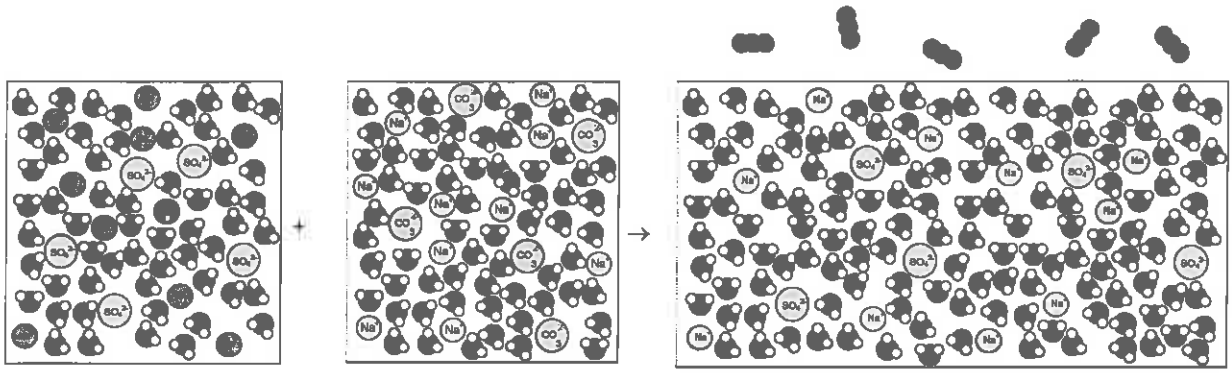
For example, in the reaction of $H_2SO_4(aq)$ with $NaOH(aq)$ we know that one lot of H_2SO_4 contains two lots of H^+ ions. As H^+ ions react with OH^- ions in the ratio 1:1 [$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$] we know that we need two lots of NaOH to provide two lots of OH^- ions to react with the two lots of H^+ ions. Therefore, one lot of H_2SO_4 reacts with two lots of NaOH, i.e. the reacting ratio of H_2SO_4 : NaOH = 1:2



H_2SO_4 (aq)
contains H^+(aq)

NaOH (aq)
contains OH^-(aq)

$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$
the $Na^+(aq)$ and $SO_4^{2-}(aq)$ ions are not involved



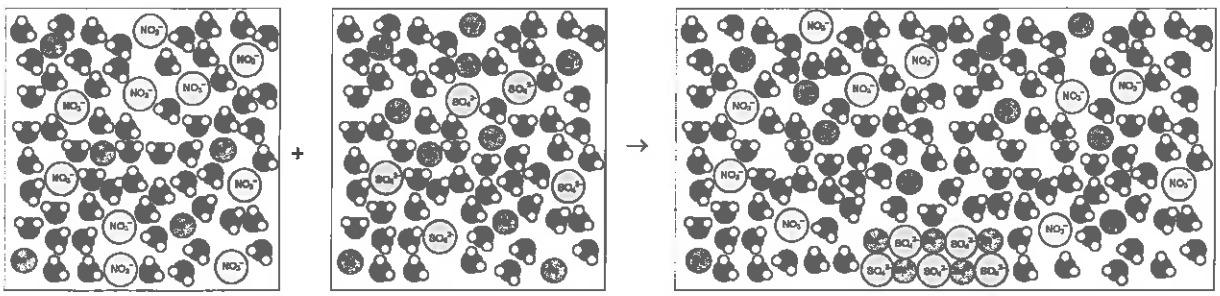
H_2SO_4 (aq)
contains H^+(aq)

Na_2CO_3 (aq)
contains CO_3^{2-}(aq)

$2\ H^+(aq) + CO_3^{2-}(aq) \rightarrow H_2O(l) + CO_2(g)$
the $Na^+(aq)$ and $SO_4^{2-}(aq)$ ions are not involved

Precipitation reactions

Some salts are insoluble in water. If solutions containing those ions are mixed, the insoluble salt forms as a solid as the solutions are mixed. This solid is known as a precipitate, and the reaction as precipitation.

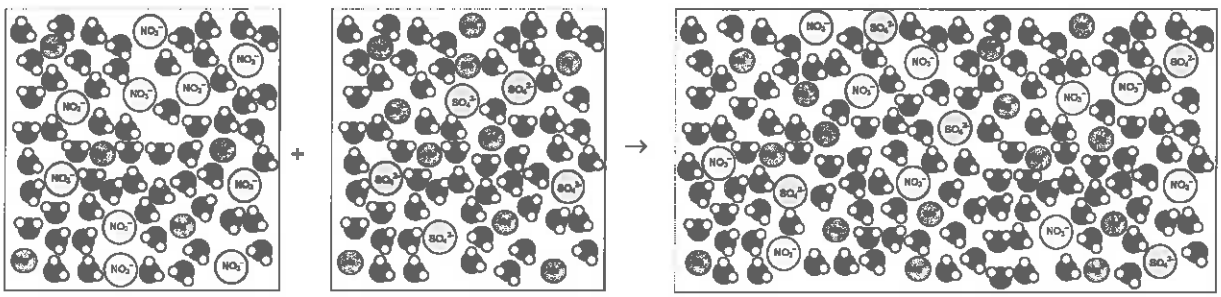


$Ba(NO_3)_2$ (aq)
contains Ba^{2+}(aq)

Na_2SO_4 (aq)
contains SO_4^{2-}(aq)

$Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$

Most salts are soluble in water. Often when solutions of two salts are mixed, no such precipitation reaction will take place and the ions will remain dissolved in water.



$Mg(NO_3)_2$ (aq)

Na_2SO_4 (aq)

Nothing happens – solutions just mix together

TASK 6 – IONIC EQUATIONS

1) Use your knowledge of ionic equations to give the molar ratio in which the following acids react with bases. Complete the table to show your answers.

Acid	Formula of acid	Base	Formula of base	Molar ratio of acid:base
hydrochloric acid		lithium hydroxide		
sulphuric acid		sodium hydrogencarbonate		
nitric acid		ammonia		
sulphuric acid		potassium carbonate		
nitric acid		strontium hydroxide		

2) Write ionic equations for each of the following reactions.

a) reaction of hydrochloric acid (aq) with potassium hydroxide (aq)

b) precipitation of silver iodide from reaction between silver nitrate (aq) and potassium iodide (aq)

c) reaction of potassium carbonate (aq) with nitric acid (aq)

d) precipitation of calcium hydroxide from reaction between sodium hydroxide (aq) and calcium chloride (aq)

e) reaction of ammonia (aq) with hydrochloric acid (aq)

f) reaction of sodium hydrogencarbonate (aq) with sulfuric acid (aq)

g) precipitation of calcium sulfate from reaction between calcium chloride (aq) and sulfuric acid (aq)

h) precipitation of lead (II) chloride from reaction between lead nitrate (aq) and sodium chloride (aq)

i) reaction of barium hydroxide (aq) with nitric acid (aq)

3 – SIGNIFICANT FIGURES & STANDARD FORM

Some general rules in chemistry:

- usually give final answers to 3 significant figures (but it is best to keep the whole number on your a during the calculation)
- give M_r's to 1 decimal place

Note: 0.00346678 = 0.00347 (3 sig fig) = 3.47×10^{-3} (3 sig fig) 346678 = 347000 (3 sig fig) = 3.47×10^{5} (3 sig fig)

TASK 7 – SIGNIFICANT FIGURES & STANDARD FORM

1) Write the following numbers to the quoted number of significant figures.

a) 345789 4 sig figs ..... d) 6 3 sig figs .....

b) 297300 3 sig figs ..... e) 0.001563 3 sig figs .....

c) 0.07896 3 sig figs ..... f) 0.01 4 sig figs .....

2) Complete the following sums and give the answers to 3 significant figures.

a) 6125 x 384 ..... d) 750 ÷ 25 .....

b) 25.00 x 0.01 ..... e) 0.000152 x 13 .....

c) 13.5 + 0.18 ..... f) 0.0125 x 0.025 .....

3) Write the following numbers in non standard form.

a) 1.5×10^{-3} ..... d) 0.0534×10^{4} .....

b) 0.046×10^{-2} ..... e) 10.3×10^{5} .....

c) 3.575×10^{5} ..... f) 8.35×10^{-3} .....

4) Write the following numbers in standard form.

a) 0.000167 ..... d) 34500 .....

b) 0.0524 ..... e) 0.62 .....

c) 0.000000015 ..... f) 87000000 .....

5) Complete the following calculations and give the answers to 3 significant figures.

a) $6.125 \times 10^{-3} \times 3.5$ .....

b) $4.3 \times 10^{-4} \div 7.0$ .....

c) $4.0 \times 10^{8} + 35000$ .....

d) $0.00156 + 2.4 \times 10^{3}$ .....

e) $6.10 \times 10^{-2} - 3.4 \times 10^{-5}$ .....

f) $8.00 \times 10^{-3} \times 0.100 \times 10^{-3}$ .....

4 – THE MOLE & AVOGADRO CONSTANT

- One mole of anything contains 6.02×10^{23} of those things. One mole of bananas is 6.02×10^{23} bananas. One mole of water molecules is 6.02×10^{23} water molecules
- This number is known as the Avogadro constant.
- The Avogadro number was chosen so that the mass of one mole of particles of a substance equals the M_r in grams. For example, the M_r of water is 18.0, and the mass of one mole of water molecules in 18.0 grams.

$$\text{Moles} = \frac{\text{Mass (in grams)}}{M_r}$$

1 ton = 1,000,000 g

1 kg = 1,000 g

1 mg = 0.001 g

Remember *Mr Moles!*

TASK 8 – MOLES

1) How many moles are there in each of the following?

a) 72 g of Mg b) 4 kg of CuO c) 39 g of $Al(OH)_3$

d) 1 tonne of NaCl e) 20 mg of $Cu(NO_3)_2$

2) What is the mass of each of the following?

a) 5 moles of Cl_2 b) 0.2 moles of Al_2O_3 c) 0.01 moles of Ag

d) 0.002 moles of $(NH_4)_2SO_4$ e) 0.3 moles of $Na_2CO_3.10H_2O$

3) a) Calculate the number of moles of CO_2 molecules in 11 g of carbon dioxide.

b) Calculate the number of moles of C atoms in 11 g of carbon dioxide.

a) Calculate the number of moles of O atoms in 11 g of carbon dioxide.

4) a) Calculate the number of moles of Al_2O_3 in 5.1 g of Al_2O_3.

b) Calculate the number of moles of Al^{3+} ions in 5.1 g of Al_2O_3.

a) Calculate the number of moles of O^{2-} ions in 5.1 g of Al_2O_3.

5) An experiment was carried out to find the M_r of vitamin C (ascorbic acid). It was found that 1 g contains 0.00568 moles of Vitamin C molecules. Calculate the M_r of vitamin C.

6) Use the following data to calculate the mass of the particles shown.

Mass of proton = 1.6726×10^{-24} g

Mass of neutron = 1.6749×10^{-24} g

Mass of electron = 9.1094×10^{-28} g

Avogadro constant = 6.0221×10^{23}

a) Calculate the mass of a ^1H atom.

b) Calculate the mass of an $^1H^+$ ion.

c) Calculate the mass of a ^3H atom.

5 – REACTING MASS CALCULATIONS

What a chemical equation means

N_2 + 3 H_2 → 2 NH_3

1 molecule N_2	3 molecules H_2	2 molecules NH_3
12 molecules N_2 2 dozen molecules N_2	36 molecules H_2 3 dozen molecules H_2	24 molecules NH_3 2 dozen molecules NH_3
12 molecule N_2 2 dozen molecules N_2	36 molecules H_2 3 dozen molecules H_2	24 molecules NH_3 2 dozen molecules NH_3
6×10^{23} molecule N_2 2 moles N_2	18×10^{23} molecules H_2 3 moles H_2	12×10^{23} molecules NH_3 2 moles NH_3
10 moles N_2	3 moles H_2	2 moles NH_3
0.5 moles N_2	1.5 moles H_2	1 mole NH_3

TASK 9 – WHAT EQUATIONS MEAN

4 Na + O_2 → 2 Na_2O

12 mol

0.1 mol

2 Al + 3 Cl_2 → 2 $AlCl_3$

5 mol

0.1 mol

C_4H_{10} + 6½ O_2 → 4 CO_2 + 5 H_2O

0.5 mol

20 mol

4 NH_3 + 3 O_2 → 2 N_2 + 6 H_2O

0.5 mol

10 mol

Reacting mass calculations

- You can use balanced chemical equations to find out what mass of chemicals (or volume of gases) react or are produced in a chemical reaction. To do this, calculate:

  (a) moles of ✓ (b) moles of ? (c) mass of ?

e.g. What mass of iron is produced when 32 kg of iron (III) oxide is heated with CO?

$$\underset{\checkmark}{Fe_2O_3(s)} + 3\,CO(g) \rightarrow \underset{?}{2\,Fe(s)} + 3\,CO_2(g)$$

$$\text{moles of } Fe_2O_3 = \frac{\text{mass (g)}}{M_r} = \frac{32{,}000}{159.6} = 200.5 \text{ mol}$$

1 mole of Fe_2O_3 forms 2 moles of Fe

$\therefore$ moles of Fe = 2 x 200.5 = 401.0 mol

$\therefore$ mass of Fe = moles x M_r = 401.0 x 55.8 = **22,400 g (3 sig fig)**

e.g. What mass of oxygen is needed to convert 102 g of ammonia into nitrogen?

$$\underset{\checkmark}{4\,NH_3(g)} + \underset{?}{3\,O_2(g)} \rightarrow 2\,N_2(g) + 6\,H_2O(g)$$

$$\text{moles of } NH_3 = \frac{\text{mass (g)}}{M_r} = \frac{102}{17.0} = 6.00 \text{ mol}$$

4 moles of NH_3 reacts with 3 moles of O_2 $\therefore$ 1 mole of NH_3 reacts with ¾ mole of O_2

$\therefore$ moles of O_2 = 6.00 x ¾ = 4.00 mol

$\therefore$ mass of O_2 = moles x M_r = 4.00 x 32.0 = **128 g (3 sig fig)**

e.g. When 5.00 g of crystals of hydrated tin (II) chloride, $SnCl_2.xH_2O$, are heated, 4.20 g of anhydrous tin (II) chloride are formed. Calculate the number of molecules of water of crystallisation are in $SnCl_2.xH_2O$ (i.e. the value of x).

$$SnCl_2.xH_2O \rightarrow SnCl_2 + x\,H_2O$$

$$\text{moles of } SnCl_2 = \frac{\text{mass (g)}}{M_r} = \frac{4.20}{189.7} = 0.02214 \text{ moles}$$

$\therefore$ moles of $SnCl_2.xH_2O$ = 0.02214 mol

$\therefore$ M_r of $SnCl_2.xH_2O$ = $\frac{\text{mass}}{\text{moles}}$ = $\frac{5.00}{0.02214}$ = 225.8

$\therefore$ M_r of xH_2O = 225.8 – 189.7 = 36.1

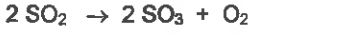
$\therefore$ x = $\frac{36.1}{18.0}$ = 2 (x is a whole number)

TASK 10 – REACTING MASS CALCULATIONS 1

1) What mass of hydrogen is needed to react with 40 g of copper oxide?

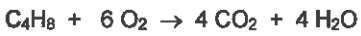
2) What mass of oxygen reacts with 192 g of magnesium?

3) What mass of sulfur trioxide is formed from 96 g of sulfur dioxide?



4) What mass of carbon monoxide is needed to react with 480 kg of iron oxide?

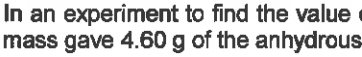
5) What mass of carbon dioxide is produced when 5.6 g of butene is burnt.



6) What mass of oxygen is needed to react with 8.5 g of hydrogen sulphide (H_2S)?

7) 4.92 g of hydrated magnesium sulphate crystals ($MgSO_4.nH_2O$) gave 2.40 g of anhydrous magnesium sulphate on heating to constant mass. Work out the formula mass of the hydrated magnesium sulphate and so the value of *n*.

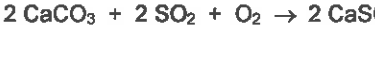
8) In an experiment to find the value of *x* in the compound $MgBr_2.xH_2O$, 7.30 g of the compound on heating to constant mass gave 4.60 g of the anhydrous salt $MgBr_2$. Find the value of *x*.



9) What mass of glucose must be fermented to give 5.00 kg of ethanol?

10) The pollutant sulfur dioxide can removed from the air by reaction with calcium carbonate in the presence of oxygen. What mass of calcium carbonate is needed to remove 1 ton of sulfur dioxide?

11) What mass of potassium oxide is formed when 7.8 mg of potassium is burned in oxygen?



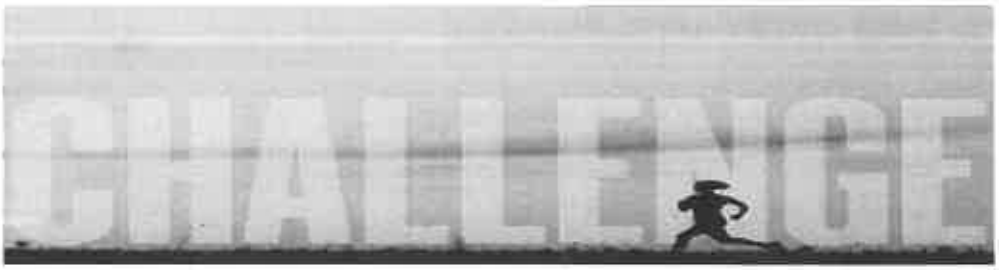
12) What mass of hydrogen is produced when 10.0 g of aluminium reacts with excess hydrochloric acid?

13) What mass of sodium just reacts with 40.0 g of oxygen?

14) What mass of nitrogen is produced when 2.00 tonnes of ammonia gas decomposes?

15) What mass of oxygen is produced when 136 g of hydrogen peroxide molecules decompose?

16) What mass of lead (II) oxide is produced when 0.400 moles of lead (II) nitrate decomposes?



1) A mixture of anhydrous sodium carbonate and sodium hydrogencarbonate of mass 10.000 g was heated until it reached a constant mass of 8.708 g. Calculate the composition of the mixture in grams of each component. Sodium hydrogencarbonate thermally decomposes to form sodium carbonate.

2) A mixture of calcium carbonate and magnesium carbonate with a mass of 10.000 g was heated to constant mass, with the final mass being 5.096 g. Calculate the percentage composition of the mixture, by mass.

3) 1 mole of a hydrocarbon of formula C_nH_{2n} was burned completely in oxygen producing carbon dioxide and water vapour only. It required 192 g of oxygen. Work out the formula of the hydrocarbon.

4) A mixture of $MgSO_4.7H_2O$ and $CuSO_4.5H_2O$ is heated at 120°C until a mixture of the anhydrous compounds is produced. If 5.00 g of the mixture gave 3.00 g of the anhydrous compounds, calculate the percentage by mass of $MgSO_4.7H_2O$ in the mixture.

Yields

- When you make a new substance by a chemical reaction, you may not get all the expected amount of product. For example, if you reacted 4 g of hydrogen with 32 g of oxygen, you may get less than 36 g of water. Reasons include:
  - the reaction may be reversible (both the forwards and backwards reaction can take place)
  - some of the product may be lost when it is separated from the reaction mixture
  - some of the reactants may react in other reactions.

$$\% \text{ yield} = \frac{\text{mass of product obtained}}{\text{maximum theoretical mass of product}} \times 100$$

e.g. Iron is extracted from iron oxide in the Blast Furnace as shown. $Fe_2O_3 + 3\,CO \rightarrow 2\,Fe + 3\,CO_2$

a) Calculate the maximum theoretical mass of iron that can be made from 1 tonne of iron oxide.

$$\text{Moles of } Fe_2O_3 = \frac{\text{mass (g)}}{M_r} = \frac{1{,}000{,}000}{159.6} = 6266 \text{ moles}$$

$\therefore$ moles of Fe = 2 x 6266 = 12530 mol

$\therefore$ mass of Fe = moles x M_r = 12530 x 55.8 = **699000 g (3 sig fig)**

b) In the reaction, only 650000 g of iron was made. Calculate the percentage yield.

$$\% \text{ Yield} = \frac{\text{mass actually made}}{\text{theoretical mass expected}} \times 100 = \frac{650000}{699000} \times 100 = 93.0\%$$

TASK 12 – PERCENTAGE YIELD

1) Sulfur dioxide reacts with oxygen to make sulfur trioxide. $2\ SO_2 + O_2 \rightarrow 2\ SO_3$

   a) Calculate the maximum theoretical mass of sulfur trioxide that can be made by reacting 96 g of sulfur dioxide with an excess of oxygen.

   b) In the reaction, only 90 g of sulfur trioxide was made. Calculate the percentage yield.

   c) Give three reasons why the amount of sulfur trioxide made is less than the maximum theoretical maximum.

2) Iron is extracted from iron oxide in the Blast Furnace as shown. $Fe_2O_3 + 3\ CO \rightarrow 2\ Fe + 3\ CO_2$

   a) Calculate the maximum theoretical mass of iron that can be made from 1 tonne of iron oxide.

   b) In the reaction, only 650000 g of iron was made. Calculate the percentage yield.

3) Nitrogen reacts with hydrogen to make ammonia. $N_2 + 3\ H_2 \rightarrow 2\ NH_3$

   a) Calculate the maximum theoretical mass of ammonia that can be made by reacting 90 g of hydrogen with an excess of nitrogen.

   b) In the reaction, only 153 g of ammonia was produced. Calculate the percentage yield.

4) Titanium can be extracted from titanium chloride by the following reaction. $TiCl_4 + 2\ Mg \rightarrow Ti + 2\ MgCl_2$

   a) Calculate the maximum theoretical mass of titanium that can be extracted from 100 g of titanium chloride .

   b) In the reaction, only 20 g of titanium was made. Calculate the percentage yield.

   c) Give three reasons why the amount of titanium made is less than the maximum theoretical maximum.

5) Aluminium is extracted from aluminium oxide in the following reaction. $2\ Al_2O_3 \rightarrow 4\ Al + 3\ O_2$

   a) Calculate the maximum theoretical mass of aluminium that can be made from 1 kg of aluminium oxide.

   b) In the reaction, only 500 g of aluminium was made. Calculate the percentage yield.

6) The fertiliser ammonium sulpfate is made as follows. $2\ NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$

   a) Calculate the maximum theoretical mass of ammonium sulfate that can be made by reacting 85 g of ammonia with an excess of sulfuric acid.

   b) In the reaction, only 300 g of ammonium sulfate was produced. Calculate the percentage yield.

7) 0.8500 g of hexanone, $C_6H_{12}O$, is converted into its 2,4-dinitrophenylhyrazone during its analysis. After isolation and purification, 2.1180 g of product $C_{12}H_{18}N_4O_4$ are obtained. Calculate the percentage yield.

Atom Economy

- Atom economy is a measure of what proportion of the products of a reaction are the desired product and how much is waste. The higher the atom economy, the less waste that is produced.

$$\text{Atom economy} = \frac{\text{mass of wanted product from equation}}{\text{total mass of products from equation}} \times 100$$

e.g. ***making ethanol by fermentation***

glucose → ethanol + carbon dioxide

$C_6H_{12}O_6(aq) \rightarrow 2\,CH_3CH_2OH(aq) + 2\,CO_2$

180 g → 92 g + 88 g (180 g products)

$$\text{Atom economy} = \frac{92}{180} \times 100 = 51\%$$

Only 92 g of the 180 g of products is ethanol. This means that 51% of the mass of the products is ethanol, while the other 49% is waste.

TASK 13 – ATOM ECONOMY

1) Calculate the atom economy to make sodium from sodium chloride. $2\,NaCl \rightarrow 2\,Na + Cl_2$

2) Calculate the atom economy to make hydrogen from the reaction of zinc with hydrochloric acid. $Zn + 2\,HCl \rightarrow ZnCl_2 + H_2$

3) Calculate the atom economy to make iron from iron oxide in the Blast Furnace. $Fe_2O_3 + 3\,CO \rightarrow 2\,Fe + 3\,CO_2$

4) Calculate the atom economy to make calcium oxide from calcium carbonate. $CaCO_3 \rightarrow CaO + CO_2$

5) Calculate the atom economy to make sulfur trioxide from sulfur dioxide. $2\,SO_2 + O_2 \rightarrow 2\,SO_3$

6) Calculate the atom economy to make oxygen from hydrogen peroxide. $2\,H_2O_2 \rightarrow 2\,H_2O + O_2$

7) Hydrazine (N_2H_4) was used as the rocket fuel for the Apollo missions to the moon. It is by reaction of ammonia (NH_3) with sodium chlorate (NaOCl).

ammonia + sodium chlorate → hydrazine + sodium chloride + water

$2\,NH_3 + NaOCl \rightarrow N_2H_4 + NaCl + H_2O$

a) Calculate the maximum theoretical mass of hydrazine that can be made by reacting 340 g of ammonia with an excess of sodium chlorate.

b) In the reaction, only 280 g of hydrazine was produced. Calculate the percentage yield.

c) Calculate the atom economy for this way of making hydrazine.

d) Explain clearly the difference between atom economy and percentage yield.

REACTING GAS VOLUMES

- The volume of a gas depends on the temperature, pressure and number of moles. What the gas is does not affect its volume.
- This means that under the same conditions of temperature and pressure, 100 cm^3 (as an example) of one gas contains the same number of moles as 100 cm^3 of any other gas.

e.g. What volume of oxygen reacts with 100 cm^3 of but-1-ene?

$C_4H_8(g) + 6\ O_2(g) \rightarrow 4\ CO_2(g) + 4\ H_2O(l)$

Answer = 600 cm^3

e.g. 1 dm^3 of but-1-ene is reacted with 10 dm^3 of oxygen. What volume of oxygen remains at the end?

$C_4H_8(g) + 6\ O_2(g) \rightarrow 4\ CO_2(g) + 4\ H_2O(l)$

6 dm^3 of O_2 reacts with 1 dm^3 of but-1-ene $\therefore$ 4 dm^3 of oxygen is left over

TASK 15 – REACTING GAS VOLUMES

1) What volume of oxygen is required to burn the following gases, and what volume of carbon dioxide is produced?

a) 1 dm^3 of methane $CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(l)$

b) 20 cm^3 of butene $C_4H_8(g) + 6\ O_2(g) \rightarrow 4\ CO_2(g) + 4\ H_2O(l)$

c) 500 cm^3 of ethyne $2\ C_2H_2(g) + 5\ O_2(g) \rightarrow 4\ CO_2(g) + 2\ H_2O(l)$

d) 750 cm^3 of benzene $2\ C_6H_6(g) + 15\ O_2(g) \rightarrow 12\ CO_2(g) + 6\ H_2O(l)$

2) When 100 cm^3 of hydrogen bromide reacts with 80 cm^3 of ammonia, a white solid is formed and some gas is left over. What gas and how much of it is left over?

$NH_3(g) + HBr(g) \rightarrow NH_4Br(s)$

3) 100 cm^3 of methane was reacted with 500 cm^3 of oxygen. What is the total volume of all gases at the end, and indicate how much there is of each gas?

$CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(l)$

4) If 4 dm^3 of hydrogen sulphide is burned in 10 dm^3 of oxygen, what is the final volume of the mixture (give the volume of each gas at the end)?

$2\ H_2S(g) + 3\ O_2(g) \rightarrow 2\ H_2O(g) + 2\ SO_2(g)$

8 – EMPIRICAL & MOLECULAR FORMULAS

- Every substance has an empirical formula. It shows the simplest ratio of atoms of each element in a substance.

  e.g. SiO_2 (giant covalent) – the ratio of Si:O atoms in the lattice is 1:2
  Al_2O_3 (ionic) – the ratio of Al^{3+}:O^{2-} ions in the lattice is 2:3
  H_2O (molecular) – the ratio of H:O atoms in the substance is 1:2

- Substances made of molecules also have a molecular formula. This indicates the number of atoms of each element in **one molecule**.

a) Finding the molecular formula from the formula mass and empirical formula

e.g. Empirical formula = CH_2, M_r = 42.0

Formula mass of empirical formula = 14.0 ∴ M_r / formula mass of empirical formula = 42.0/14.0 = 3

Molecular formula = 3 x empirical formula = C_3H_6

b) Finding the empirical formula of a compound from its composition by percentage or mass

i) Write out the mass or percentage of each element,

ii) Divide each mass or percentage by the A_r of the element **(not the M_r)**

iii) Find the simplest whole number ratio of these numbers by dividing by the smallest number. If the values come out as near $^1/_2$'s then times them by 2, if they are near $^1/_3$'s then times by 3.

e.g. i) A compound is found to contain, by mass, iron 72.4% and oxygen 27.6%.

Fe $\frac{72.4}{56}$ = 1.29 O $\frac{27.6}{16}$ = 1.73

Simplest ratio Fe:O = 1.29 : 1.73 (divide by smallest, i.e. 1.29)

1 : 1.34 (involves $^1/_3$'s so x3)

3 : 4

∴ empirical formula = **Fe_3O_4**

e.g. ii) 0.25 g of hydrogen reacts with oxygen to produce 4.25 g of hydrogen peroxide (M_r = 34.0).

Mass of oxygen reacting with hydrogen = 4.25 – 0.25 = 4.00 g

H $\frac{0.25}{1}$ = 0.25 O $\frac{4.00}{16}$ = 0.25

Simplest ratio H:O = 0.25 : 0.25 (divide by smallest, i.e. 0.25)

1 : 1

∴ empirical formula = **HO**

Formula mass of empirical formula = 17.0

∴ M_r / formula mass of empirical formula = 34.0/17.0 = 2

Molecular formula = 2 x empirical formula = **H_2O_2**

TASK 18 – EMPRICIAL & MOLECULAR FORMULAS

1) Write the empirical formula of each of the following substances.

a)	C_2H_6	b)	P_2O_3	c)	SO_2	d)	C_6H_{12}
e)	$C_2H_4O_2$	f)	C_2H_7N	g)	B_6H_{10}	h)	$C_{12}H_{22}O_{11}$

2) The empirical formula and relative molecular mass of some simple molecular compounds are shown below. Work out the molecular formula of each one.

a)	NH_2	$M_r = 32$	d)	PH_3	$M_r = 34$
b)	C_2H_5	$M_r = 58$	e)	CH	$M_r = 78$
c)	CH_2	$M_r = 70$	f)	CH_2	$M_r = 42$

3) Find the simplest whole number ratio for each of the following. The numbers come from experiments so there will be some small random errors which mean that you can round the numbers a little bit.

a)	1.5 : 1	b)	1 : 1.98	c)	4.97 : 1	d)	1 : 2.52
e)	1 : 1.33	f)	1.66 : 1	g)	1 : 1.26	h)	1 : 1.74

4) Find the empirical formulae of the following compounds using the data given.

a)	Ca	20 %	Br	80 %			
b)	Na	29.1 %	S	40.5 %	O	30.4 %	
c)	C	53.3 %	H	15.5 %	N	31.1 %	
d)	C	2.73 g	O	7.27 g			
e)	N	15.2 g	O	34.8 g			

5) 3.53 g of iron reacts with chlorine to form 10.24 g of iron chloride. Find the empirical formula of the iron chloride.

6) 50.0 g of a compound contains 22.4 g of potassium, 9.2 g of sulphur, and the rest oxygen. Calculate the empirical formula of the compound.

7) An oxide of phosphorus contains 56.4 % phosphorus and 43.6 % oxygen. Its relative molecular mass is 220. Find both the empirical and the molecular formula of the oxide.

8) A compound contains 40.0 g of carbon, 6.7 g of hydrogen and 53.5 g of oxygen. It has a relative molecular formula of 60. Find both the empirical and the molecular formula of the compound.

9) An organic compound X, which contains carbon, hydrogen and oxygen only, has an M_r of 85. When 0.43 g of X are burned in excess oxygen, 1.10 g of carbon dioxide and 0.45 g of water are formed. Find the empirical and molecular formulae of compound X.

10) When ammonium dichromate (VI) is added gradually to molten ammonium thiocyanate, Reinecke's salt is formed. It has the formula $NH_4[Cr(SCN)_x(NH_3)_y]$ and the following composition by mass: Cr = 15.5%, S = 38.15%, N = 29.2%. Calculate the values of x and y in the above formula.

Calculation Allsorts

1) A compound contains 59.4% carbon, 10.9% hydrogen, 13.9% nitrogen and 15.8% oxygen, by mass. Find the empirical formula of the compound.

2) A compound containing carbon, hydrogen and oxygen only contains 74.2% carbon and 7.9% hydrogen. Its M_r is found to be 178 by mass spectroscopy. Find its empirical and molecular formulae.

3) What mass of carbon monoxide is needed to react with 1.00 kg of iron oxide?

$$Fe_2O_3 + 3\,CO \rightarrow 2\,Fe + 3\,CO_2$$

4) The reaction below is known as the Thermitt reaction, which is used to form molten iron to mould train tracks together. What mass of aluminium powder is needed to react with 8.00 g of iron (III) oxide?

$$2\,Al + Fe_2O_3 \rightarrow Al_2O_3 + 2\,Fe$$

5) What volume of 0.100 mol dm^{-3} hydrochloric acid would react with 25.0 g of calcium carbonate?

$$CaCO_3 + 2\,HCl \rightarrow CaCl_2 + CO_2 + H_2$$

6) 25.0 cm^3 of 0.0400 mol dm^{-3} sodium hydroxide solution reacted with 20.75 cm^3 of sulphuric acid in a titration. Find the concentration of the sulphuric acid.

7) 13.8 g of a solid monoprotic acid was dissolved in water and made up to 250 cm^3. 25.0 cm^3 portions of this were titrated against 0.250 mol dm^{-3} sodium hydroxide, requiring 23.5 cm^3. Calculate the M_r of the acid.

8) 10.0 g of a mixture of copper powder and magnesium powder was mixed with 100 cm^3 of 1.00 mol dm^{-3} hydrochloric acid. The copper does not react, but the magnesium does as shown:

$$Mg + 2\,HCl \rightarrow MgCl_2 + H_2$$

The resulting solution was filtered to remove unreacted copper and then made up to 250 cm^3 with water. 25.0 cm^3 of this solution was found to neutralise 36.8 cm^3 of 0.200 mol dm^{-3} NaOH. Find the % by mass of the magnesium in the metal powder mixture.

9) 12.0 g of a mixture of calcium carbonate and sodium chloride was treated with 100 cm^3 of 2.00 mol dm^{-3} hydrochloric acid (only the calcium carbonate reacts). The resulting solution was made up to 250 cm^3 with water and a 25.0 cm^3 portion of this needed 34.1 cm^3 of 0.200 mol dm^{-3} sodium hydroxide for neutralisation. Find the % by mass of the calcium carbonate in the mixture.

10) The solid booster rockets of the space shuttle are fuelled by a mixture of aluminium and ammonium chlorate (VII) (NH_4ClO_4).

a) If no other reagents are involved, and the products are nitrogen, water, hydrogen chloride and aluminium oxide, devise an equation for this reaction.

b) Each launch consumes about 160 tonnes of aluminium. What mass of hydrogen chloride gas is produced in the atmosphere above the Cape Canaveral launch pad?