AMOUNT OF SUBSTANCE

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

TASK 2 – WRITING FORMULAS 1

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

TASK 3 – WRITING FORMULAS 2

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

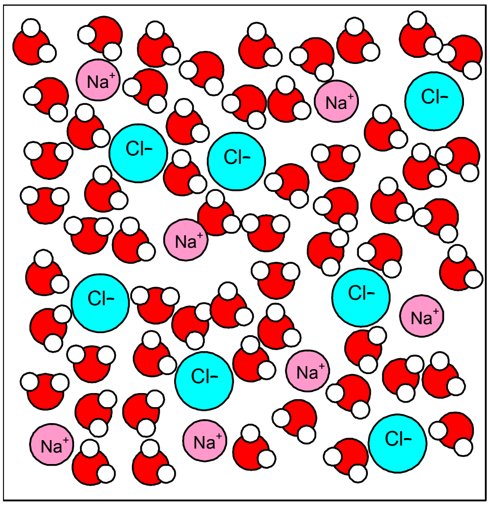
10) reaction of zinc with phosphoric acid

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.

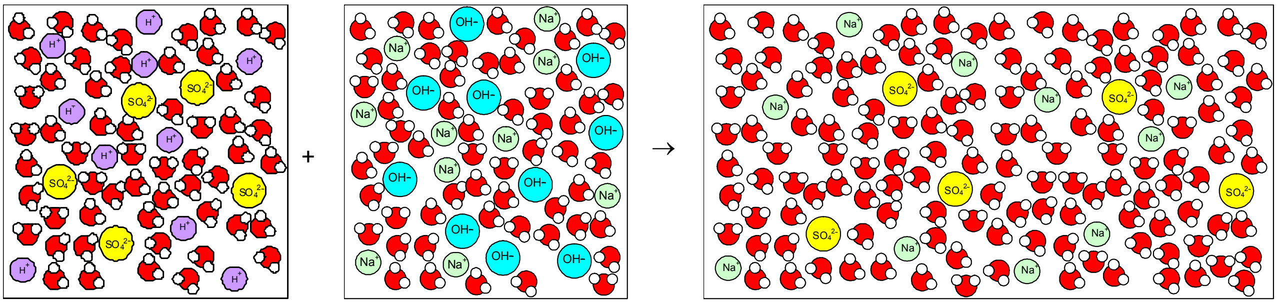
Simple examples are equations for which ionic equations can be written include:

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

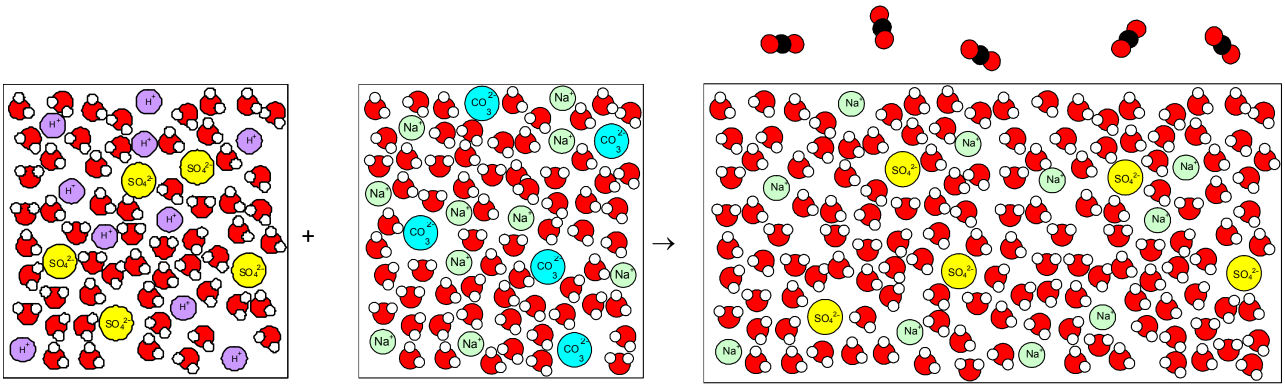


H_2SO_4 (aq) contains H^+(aq)

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)

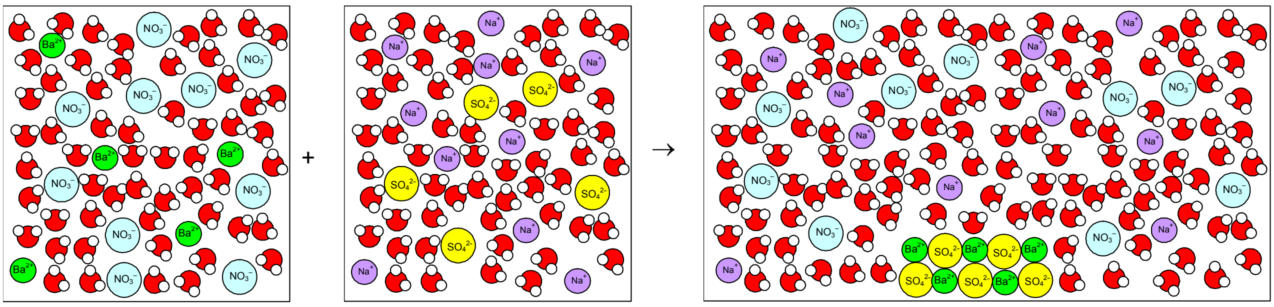
Na_2CO_3 (aq) contains CO_3^{2-}(aq)

$2\,H^+(aq) + CO_3^{2-}(aq) \rightarrow H_2O(l) + CO_2(g)$

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.

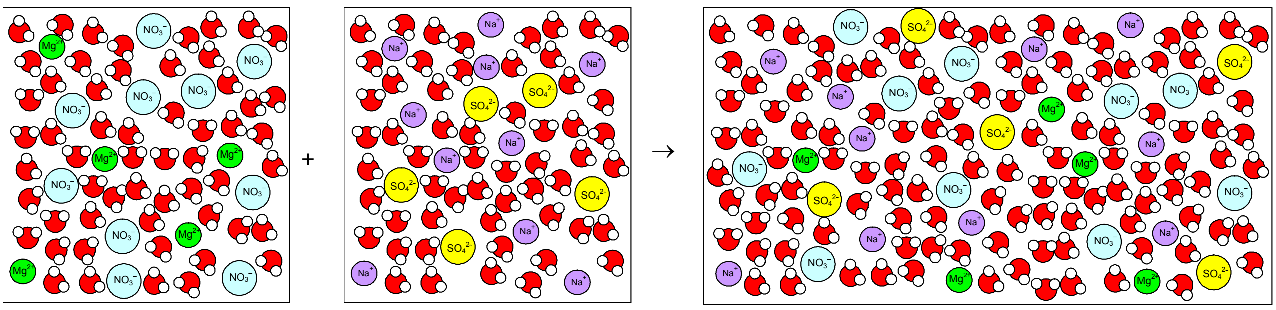


$Ba(NO_3)_2$ (aq) contains Ba^{2+}(aq)

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.

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.

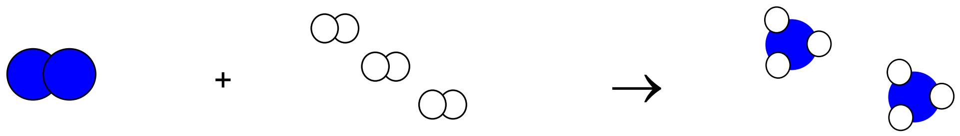
6) Use the following data to calculate the mass of the particles shown.

   Mass of proton = 1.6726×10^{-24} g Mass of electron = 9.1094×10^{-28} g
   Mass of neutron = 1.6749×10^{-24} g Avogadro constant = 6.0221×10^{23}

   a) Calculate the mass of a ^{1}H atom.
   b) Calculate the mass of an $^{1}H^{+}$ ion.
   c) Calculate the mass of a ^{3}H 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 1 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 1 mole 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		30 moles H_2		20 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?

✓ ?

$Fe_2O_3(s) + 3\ CO(g) \rightarrow 2\ Fe(s) + 3\ CO_2(g)$

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

✓ ?

$4\ NH_3(g) + 3\ O_2(g) \rightarrow 2\ N_2(g) + 6\ H_2O(g)$

moles of $NH_3 = \frac{\text{mass (g)}}{M_r} = \frac{102}{17.0} = 6.00$ 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 = 4.50 mol

$\therefore$ mass of O_2 = moles x M_r = 4.50 x 32.0 = **144 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).

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

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

$CuO + H_2 \rightarrow Cu + H_2O$

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

$2\ Mg + O_2 \rightarrow 2\ MgO$

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

$2\ SO_2 + O_2 \rightarrow 2\ SO_3$

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

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

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

$C_4H_8 + 6\ O_2 \rightarrow 4\ CO_2 + 4\ H_2O$

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

$2\ H_2S + 3\ O_2 \rightarrow 2\ SO_2 + 2\ H_2O$

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*.

$MgSO_4.nH_2O \rightarrow MgSO_4 + n\ H_2O$

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*.

$MgBr_2.xH_2O \rightarrow MgBr_2 + x\ H_2O$

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

$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$

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?

$2\ CaCO_3 + 2\ SO_2 + O_2 \rightarrow 2\ CaSO_4 + 2\ CO_2$

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

$4\ K + O_2 \rightarrow 2\ K_2O$

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

$2\ Al + 6\ HCl \rightarrow 2\ AlCl_3 + 3\ H_2$

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

$4\ Na + O_2 \rightarrow 2\ Na_2O$

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

$2\ NH_3 \rightarrow N_2 + 3\ H_2$

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

$2\ H_2O_2 \rightarrow 2\ H_2O + O_2$

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

$2\ Pb(NO_3)_2 \rightarrow 2\ PbO + 4\ NO_2 + O_2$

Limiting reagents

- In the real world of chemistry, it is rare that we react the exact right amount of chemicals together. Usually, we have more than we need of one of the reactants and so it doesn't all react – it is in excess.
- Sometimes in calculations, we need to work out if one of the reactants is in excess. The reactant that is not in excess is sometimes called the limiting reagent.

e.g. 1 - Starting point - Working out how much reacts in terms of moles: $2\ SO_2 + O_2 \rightarrow 2\ SO_3$

Moles at the start		Moles reacting		Reagent in excess	Moles at the end		
Moles SO_2	Moles O_2	Moles SO_2	Moles O_2		Moles SO_2	Moles O_2	Moles SO_3
4	3	4	2	O_2	0	1	4
10	10						
0.1	0.02						
2	0.4						
2	10						

And then you usually have to work out the mass of one of the substances.

e.g. 2 $Ba(OH)_2 + 2\ HCl \rightarrow BaCl_2 + 2\ H_2O$

Moles at the start		Moles reacting		Reagent in excess	Moles at the end		
Mol $Ba(OH)_2$	Moles HCl	Mol $Ba(OH)_2$	Moles HCl		Mol $Ba(OH)_2$	Moles HCl	Moles $BaCl_2$
5	5	2.5	5	$Ba(OH)_2$			
0.1	0.05						
0.2	0.5						
0.025	0.0375						

e.g. 3 In the manufacture of titanium, what mass of titanium can theoretically be formed when 1 kg of titanium chloride reacts with 0.1 kg of magnesium?

$$TiCl_4 + 2\ Mg \rightarrow Ti + 2\ MgCl_2$$

Moles $TiCl_4$ = $\frac{1000}{189.9}$ = 5.266 Moles Mg = $\frac{100}{24.3}$ = 4.115

5.266 moles of $TiCl_4$ needs 10.53 moles of Mg to react,

∴ $TiCl_4$ is in XS and does not all react, so Mg is the limiting reagent

∴ 2.058 moles of $TiCl_4$ reacts with 4.115 moles of Mg

∴ 2.058 moles of Ti is produced

Mass of Ti = 2.058 x 47.9 = 98.6 g

TASK 11 – REACTING MASS CALCULATIONS 2

1) In each case work out the limiting reagent and moles of ammonia formed (assuming complete reaction).

$$N_2 + 3\,H_2 \rightarrow 2\,NH_3$$

a) 3 moles of N_2 + 3 moles of H_2
b) 3 moles of N_2 + 10 moles of H_2
c) 0.1 moles of N_2 + 0.2 moles of H_2
d) 0.5 moles of N_2 + 2.0 moles of H_2
e) 2 moles of N_2 + 10 moles of H_2

2) In each case work out the limiting reagent and moles of sulphur dioxide formed (assuming complete reaction).

$$2\,SO_2 + O_2 \rightarrow 2\,SO_3$$

a) 3 moles of SO_2 + 3 moles of O_2
b) 3 moles of SO_2 + 2 moles of O_2
c) 0.1 moles of SO_2 + 0.02 moles of O_2
d) 2.0 moles of SO_2 + 0.4 moles of O_2
e) 2 moles of SO_2 + 10 moles of O_2

3) 5.00 g of iron and 5.00 g of sulphur are heated together to form iron (II) sulphide. Which reactant is in excess and what is the maximum mass of iron (II) sulphide that can be formed?

$Fe + S \rightarrow FeS$

4) In the manufacture of the fertiliser ammonium sulphate, what is the maximum mass of ammonium sulphate that can be obtained from 2.00 kg of sulphuric acid and 1.00 kg of ammonia?

$H_2SO_4 + 2\,NH_3 \rightarrow (NH_4)_2SO_4$

5) In the Solvay process, ammonia is recovered by the reaction shown. What is the maximum mass of ammonia that can be recovered from 2 tonnes of ammonium chloride and 0.5 tonnes of calcium oxide?

$2\,NH_4Cl + CaO \rightarrow CaCl_2 + H_2O + 2\,NH_3$

6) In the manufacture of titanium, what mass of titanium can theoretically be formed when 0.5 kg of titanium chloride reacts with 0.1 kg of magnesium?

$TiCl_4 + 2\,Mg \rightarrow Ti + 2\,MgCl_2$

7) In the manufacture of ammonia, what mass of ammonia can theoretically be formed when 1 kg of nitrogen reacts with 0.5 kg of hydrogen?

$N_2 + 3\,H_2 \rightarrow 2\,NH_3$

8) In the manufacture of sulphur troxide, what mass of sulphur trioxide can theoretically be formed when 1 kg of sulphur dioxide reacts with 0.5 kg of oxygen?

$2\,SO_2 + O_2 \rightarrow 2\,SO_3$

9) Hydrazine (N_2H_4) was used as the rocket fuel for the Apollo missions to the moon. It is by reaction of ammonia with sodium chlorate. What mass of hydrazine is made by reaction of 100 g of ammonia with 100 g of sodium chloriate?

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

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
$C_6H_{12}O_6(aq)$	→	$2\ CH_3CH_2OH(aq)$	+	$2\ CO_2$
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.

6 – GAS CALCULATIONS

THE IDEAL GAS EQUATION

PV = nRT

P = pressure (Pa)
V = volume (m^3)
n = number of moles
R = gas constant (8.31 J mol^{-1} K^{-1})
T = temperature (K)

Volume		Pressure		Temperature
$\frac{dm^3}{1000} = m^3$	$\frac{cm^3}{1000000} = m^3$	kPa x 1000 = Pa	MPa x 1000000 = Pa	°C + 273 = K

e.g. Calculate the pressure exerted by 0.100 moles of an ideal gas at 50°C with a volume of 1500 cm^3.

$P = \frac{nRT}{V} = \frac{0.100 \times 8.31 \times 323}{^{1500}/_{1000000}} =$ **179000 Pa** (3 sf)

TASK 14 – THE IDEAL GAS EQUATION

1) Convert the following into SI units.
a) 200ºC b) 98 kPa c) 50 cm^3 d) -50ºC e) 0.1 MPa f) 3.2 dm^3

2) Calculate the volume that 0.400 moles of an ideal gas occupies at 100ºC and a pressure of 1000 kPa.

3) How many moles of gas occupy 19400 cm^3 at 27ºC and 1 atm pressure?

4) Calculate the pressure that 0.05 moles of gas, which occupies a volume of 200 cm^3, exerts at a temperature of 50 K.

5) 0.140 moles of a gas has a volume of 2.00 dm^3 at a pressure of 90 kPa. Calculate the temperature of the gas.

6) At 273 K and 101000 Pa, 6.319 g of a gas occupies 2.00 dm^3. Calculate the relative molecular mass of the gas.

7) Find the volume of ethyne (C_2H_2) that can be prepared from 10.0 g of calcium carbide at 20ºC and 100 kPa.
$CaC_2(s) + 2 H_2O(l) \rightarrow Ca(OH)_2(aq) + C_2H_2(g)$

8) What mass of potassium chlorate (V) must be heated to give 1.00 dm^3 of oxygen at 20ºC and 0.1 MPa.
$2 KClO_3(s) \rightarrow 2 KCl(s) + 3 O_2(g)$

9) What volume of hydrogen gas, measured at 298 K and 100 kPa, is produced when 1.00 g of sodium is reacted with excess water?
$2 Na + 2 H_2O \rightarrow 2 NaOH + H_2$

10) What volume of carbon dioxide gas, measured at 800 K and 100 kPa, is formed when 1 kg of propane is burned in a good supply of oxygen?
$C_3H_8 + 5 O_2 \rightarrow 3 CO_2 + 4 H_2O$

11) Calculate the relative molecular mass of a gas which has a density of 2.615 g dm^{-3} at 298 K and 101 kPa.

12) A certain mass of an ideal gas is in a sealed vessel of volume 3.25 dm^3. At a temperature of 25ºC it exerts a pressure of 101 kPa. What pressure will it exert at 100ºC?

13) An ideal gas occupies a volume of 2.75 dm^3 at 290K and 8.7×10^4 Pa. At what temperature will it occupy 3.95 dm^3 at 1.01×10^5 Pa?

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)?

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

1) A gas has a density of 1.655 g dm^{-3} at 323 K and 1.01 x 10^5 Pa. Calculate the M_r of the gas.

2) One method used to inflate air bags in cars is to use nitrogen produced chemically from the decomposition of sodium azide. The sodium formed reacts with potassium nitrate to give more nitrogen.

$$2\ NaN_3(s) \rightarrow 2\ Na(s) + 3\ N_2(g)$$

$$10\ Na(s) + 2\ KNO_3(s) \rightarrow K_2O(s) + 5\ Na_2O(s) + N_2(g)$$

a) In what ratio (by mass) must the sodium azide and potassium nitrate be mixed in order that no metallic sodium remains after the reaction?

b) Calculate the total mass of the solid mixture needed to inflate a 60 dm^3 air bag at room temperature and atmospheric pressure.

3) 1.00 g of sulphur dissolved completely in an excess of liquid ammonia to give 420 cm^3 of hydrogen sulphide (H_2S), measured at 273 K and 101 kPa, and also a solid containing the elements nitrogen and sulphur. Deduce the empirical formula of the solid.

4) When 15 cm^3 of a gaseous hydrocarbon was exploded with 60 cm^3 of oxygen (an XS), the final volume was 45 cm^3. This decreased to 15 cm^3 on treatment with NaOH solution (removes CO_2). What was the formula of the hydrocarbon? (all measurements were made at room temperature and pressure, ∴ the water produced is a liquid).

5) Find the equation to calculate the root mean square velocity of gas particles. Once you have that equation, use it to calculate the root mean square velocity for nitrogen molecules at 298 K and 100 kPa.

6) 10 cm^3 of a hydrocarbon, C_xH_y, were exploded with an excess of oxygen. There was a contraction in volume of 30 cm^3. When the products were treated with sodium hydroxide (which reacts with carbon dioxide), there was a further contraction of 30 cm^3. Deduce the formula of the hydrocarbon, given that all volumes were measured under the same conditions.

1) Give the formula of each of the following substances.

a) zinc nitrate ....
b) lead ....
c) chromium (III) oxide ....
d) ammonium sulphate ....
e) phosphorus ....
f) nitrogen ....
g) barium hydroxide ....
h) aluminium sulphate .... (8)

2) 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. (4)

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

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

a) reaction of sulphuric acid (aq) and sodium hydroxide (aq)

.... (2)

b) precipitation of barium carbonate by mixing solutions of barium hydroxide and sodium carbonate

.... (2)

c) reaction of nitric acid (aq) and ammonia (aq)

.... (2)

d) reaction of sulphuric acid (aq) and potassium hydrogencarbonate (aq)

.... (2)

4) a) Define the term relative atomic mass. ……………………………………………………………………………

…… (2)

b) Explain why ^{12}C is referred to in the definition. ……………………………………………………………

…… (1)

c) Explain why carbon has a relative atomic mass of 12.011 and not exactly 12.000. ………………………...

…… (1)

5) In each case work out the limiting reagent and moles of ammonia formed (assuming complete reaction).

$$N_2 + 3\,H_2 \rightarrow 2\,NH_3$$

a) 5 moles of N_2 + 5 moles of H_2 moles of NH_3 formed = ………….. (1)

b) 2 moles of N_2 + 5 moles of H_2 moles of NH_3 formed = ………….. (1)

c) 10 moles of N_2 + 50 moles of H_2 moles of NH_3 formed = ………….. (1)

d) 0.2 moles of N_2 + 0.05 moles of H_2 moles of NH_3 formed = ………….. (1)

6) Calculate the volume of 0.200 moles of carbon dioxide at 100°C and 2 MPa pressure.

……

……

……

…… (3)

7) Calculate the number of moles of argon in 200 cm^3 at 100 kPa at 20°C.

……

……

……

…… (3)

8) The equation is for the combustion of ethane in oxygen. $C_2H_6(g) + 3\frac{1}{2}\,O_2(g) \rightarrow 2\,CO_2(g) + 3\,H_2O(l)$

What volume of carbon dioxide is formed and what is the total volume of gases at the end in each of the following reactions.

a) 100 cm^3 of ethane + 100 cm^3 of oxygen

volume of CO_2 formed = …………………. Total volume of gases at end = ……………………. (2)

b) 100 cm^3 of ethane + 500 cm^3 of oxygen

volume of CO_2 formed = …………………. Total volume of gases at end = ……………………. (2)

c) 200 cm^3 of ethane + 400 cm^3 of oxygen

volume of CO_2 formed = …………………. Total volume of gases at end = ……………………. (2)

9) What volume of hydrogen is formed at 20°C and 100000 Pa pressure when 2 g of magnesium is reacted with excess sulphuric acid?

$$Mg(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2(g)$$

………

………

………

……… (4)

10) What volume of carbon monoxide is formed at 1200°C and 0.14 MPa pressure when 1 kg of iron oxide is reduced by carbon?

$$Fe_2O_3(s) + 3\ C(s) \rightarrow 2\ Fe(l) + 3\ CO(g)$$

………

………

………

……… (4)

11) a) In 20 moles of Al_2O_3,

i) how many moles of Al^{3+} ions? ……………………………………………………………………………

ii) how many moles of O^{2-} ions? …………………………………………………………………………… (2)

b) In 360 g of water

i) how many moles of H atoms? ……………………………………………………………………………

ii) how many moles of O atoms? …………………………………………………………………………… (2)

c) In 1 kg of aluminium sulphate

i) how many moles of aluminium ions?……………………………………………………………………

ii) how many moles of sulphate ions? …………………………………………………………………… (2)

12) What mass of Fe_3O_4 is produced when 140 g of iron reacts with excess steam?

$$3\ Fe(s) + 4\ H_2O(g) \rightarrow Fe_3O_4(s) + 4\ H_2(g)$$

………

………

……… (3)

13) What mass of potassium oxide is formed when 7.8 g of potassium is burned in oxygen?

$$4\ K + O_2 \rightarrow 2\ K_2O$$

………

………

……… (3)

14) a) Sulfur trioxide is made from sulfur dioxide by the following reaction. Calculate the maximum amount of sulfur trioxide that can be made from 1 kg of sulfur dioxide.

$$2\ SO_2 + O_2 \longrightarrow 2\ SO_3$$

………

………

……… (3)

b) In an experiment, only 1200 g of sulfur trioxide was produced.

i) Calculate the percentage yield. …………………………………………………………………………

…… (1)

ii) Give three reasons why the yield is less than 100%.

……

……

…… (1)

c) Calculate the atom economy for this process.……………………………………………………………….. (1)

15) a) Aluminium is made from aluminium oxide by electrolysis. Calculate the mass of aluminium that can be made from 1 kg of aluminium oxide.

$$2\ Al_2O_3 \rightarrow 4\ Al + 3\ O_2$$

………

………

……… (3)

b) Calculate the percentage yield if 500 g of aluminium is produced.

……… (1)

c) Calculate the atom economy for this process.

……… (1)

16) When 12.3 g of $MgSO_4.nH_2O$ is heated gently until no further change in mass occurs, to remove the water of crystallisation, 6.0 g of anhydrous magnesium sulfate ($MgSO_4$) remained. Work out the relative formula mass (M_r) of the $MgSO_4.nH_2O$, and so the value of *n*.

$$MgSO_4.nH_2O \rightarrow MgSO_4 + n\ H_2O$$

………

………

………

………

……… (4)

17) Since 1850, most books and documents have been printed on acidic paper which, over time, becomes brittle and disintegrates. By treating books with diethyl zinc vapour, the acids in the book are neutralised. Diethyl zinc vapour penetrates the closed book and reacts with the small amount of water in the paper to form zinc oxide. The zinc oxide neutralises the acids and protects the book from acids that may be formed later. There is virtually no difference between treated and untreated books.

The reaction between diethyl zinc and water is represented by the equation:

$$Zn(C_2H_5)_2(g) + H_2O(l) \rightarrow ZnO(s) + 2\ C_2H_6(g)$$

The total moisture content of a book which was treated was found to be 0.9 g of water.

a) i) How many moles of water were present in the book? ………………………………………………….

……….. (1)

ii) Using the equation, how many moles of diethyl zinc would react with this amount of water?

……….. (1)

iii) What is the volume at room temperature and pressure of this amount of diethyl zinc vapour?

………..

………..

……….. (1)

iv) What mass of zinc oxide would be formed in the book? ………………………………………..………

……….. (2)

b) The acid content of the book was found to be 0.032 moles of $H^+_{(aq)}$. The equation for the reaction between zinc oxide and acid is:

$$ZnO(s) + 2\ H^+(aq) \rightarrow Zn^{2+}(aq) + H_2O(l)$$

i) Calculate the mass of zinc oxide required to neutralise the acid in the book.

……….. (2)

ii) Hence calculate the mass of excess zinc oxide which remains in the book.

………..

……….. (2)

7 – SOLUTION CALCULATIONS

Normal solution calculations

a) Use the volume and concentration of one reactant to calculate the moles.

b) Use the chemical equation to find the moles of the other reactant.

c) Calculate the volume or concentration as required of that reactant.

$$\textbf{concentration (mol/dm}^3\textbf{)} = \frac{\textbf{moles}}{\textbf{volume (dm}^3\textbf{)}}$$

Note

- Volume in $dm^3 = \frac{\text{volume in cm}^3}{1000}$
- In many titrations, a standard solution of one the reagents is made (typically 250 cm^3 in a volumetric flask), and 25 cm^3 portions of this standard solution are used in each titration
- Monoprotic acids contain one H^+ ion per unit (e.g. HCl, HNO_3, CH_3COOH) – with NaOH they react in the ratio 1:1 (acid : NaOH)
- Diprotic acids contain two H^+ ions per unit (e.g. H_2SO_4) – with NaOH they react in the ratio 1:2 (acid : NaOH)
- Triprotic acids contain three H^+ ions per unit (e.g. H_3PO_4) – with NaOH they react in the ratio 1:3 (acid : NaOH)

E.g. 1: 25.0 cm^3 of 0.020 mol/dm^3 sulphuric acid neutralises 18.6 cm^3 of sodium hydroxide solution.

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

a) Find the concentration of the sodium hydroxide solution in mol/dm^3.

Moles of H_2SO_4 = conc x vol (dm^3) = 0.020 x $^{25}/_{1000}$ = 0.000500

Moles of NaOH = conc x vol (dm^3) = 2 x moles H_2SO_4 = 0.000500 x 2 = 0.00100

Concentration of NaOH = $\frac{\text{mol}}{\text{vol (dm}^3)} = \frac{0.00100}{(^{18.6}/_{1000})}$ = **<u>0.0538 mol/dm³</u>**

b) Find the concentration of the sodium hydroxide solution in g/dm^3.

M_r of NaOH = 23.0 + 16.0 + 1.0 = 40.0

Mass of NaOH in 1 dm^3 = M_r x moles = 40.0 x 0.0538 = 2.15 g

Concentration = **<u>2.15 g/dm³</u>**

E.g. 2: Crystals of citric acid contain water of crystallisation ($C_6H_8O_7.nH_2O$). Citric acid is a triprotic acid. 1.52 g of the citric acid was made up to 250 cm^3 solution. 25 cm^3 portions of this solution required 21.80 cm^3 of 0.100 mol dm^{-3} for neutralisation. Calculate the value of n.

Moles of NaOH = conc x vol (dm^3) = 0.100 x $^{21.70}/_{1000}$ = 0.00218

Moles of $C_6H_8O_7.nH_2O$ in each titration = 0.00218 / 3 = 0.000727 (1 mol of acid reacts with 3 mol of NaOH)

Moles of $C_6H_8O_7.nH_2O$ in 250 cm^3 solution = 0.000727 x 10 = 0.00727

M_r of $C_6H_8O_7.nH_2O$ = $\frac{\text{mass}}{\text{moles}} = \frac{1.52}{0.00727}$ = 209.2

M_r of nH_2O = 209.2 – 192.1 = 17.1

n = $\frac{17.1}{18.0}$ = 0.950 = 1 (n is a whole number)

TASK 16 – SOLUTION CALCULATIONS

1) Calculate the number of moles in the following.

a) 2 dm^3 of 0.05 mol dm^{-3} HCl

b) 50 litres of 5 mol dm^{-3} H_2SO_4

c) 10 cm^3 of 0.25 mol dm^{-3} KOH

2) Calculate the concentration of the following in **both** mol dm^{-3} and g dm^{-3}

a) 0.400 moles of HCl in 2.00 litres of solution

b) 12.5 moles of H_2SO_4 in 5.00 dm^3 of solution

c) 1.05 g of NaOH in 500 cm^3 of solution

3) Calculate the volume of each solution that contains the following number of moles.

a) 0.00500 moles of NaOH from 0.100 mol dm^{-3} solution

b) 1.00 x 10^{-5} moles of HCl from 0.0100 mol dm^{-3} solution

4) 25.0 cm^3 of 0.020 mol dm^{-3} sulphuric acid neutralises 18.6 cm^3 of barium hydroxide solution.

$$H_2SO_4 + Ba(OH)_2 \rightarrow BaSO_4 + 2 H_2O$$

a) Find the concentration of the barium hydroxide solution in mol dm^{-3}.

b) Find the concentration of the barium hydroxide solution in g dm^{-3}.

5) 25.0 cm^3 of a solution of sodium hydroxide required 18.8 cm^3 of 0.0500 mol dm^{-3} H_2SO_4.

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

a) Find the concentration of the sodium hydroxide solution in mol dm^{-3}.

b) Find the concentration of the sodium hydroxide solution in g dm^{-3}.

6) Calculate the volume of 0.05 mol dm^{-3} KOH is required to neutralise 25.0 cm^3 of 0.0150 mol dm^{-3} HNO_3.

$$HNO_3 + KOH \rightarrow KNO_3 + H_2O$$

7) 25.0 cm^3 of arsenic acid, H_3AsO_4, required 37.5 cm^3 of 0.100 mol dm^{-3} sodium hydroxide for neutralisation.

$$3 NaOH(aq) + H_3AsO_4(aq) \rightarrow Na_3AsO_4(aq) + 3 H_2O(l)$$

a) Find the concentration of the acid in mol dm^{-3}.

b) Find the concentration of the acid in g dm^{-3}.

8) A 250 cm^3 solution of NaOH was prepared. 25.0 cm^3 of this solution required 28.2 cm^3 of 0.100 mol dm^{-3} HCl for neutralisation. Calculate what mass of NaOH was dissolved to make up the original 250 cm^3 solution.

$$HCl + NaOH \rightarrow NaCl + H_2O$$

9) What volume of 5.00 mol dm^{-3} HCl is required to neutralise 20.0 kg of $CaCO_3$?

$$2 HCl + CaCO_3 \rightarrow CaCl_2 + H_2O + CO_2$$

10) 3.88 g of a monoprotic acid was dissolved in water and the solution made up to 250 cm^3. 25.0 cm^3 of this solution was titrated with 0.095 mol dm^{-3} NaOH solution, requiring 46.5 cm^3. Calculate the relative molecular mass of the acid.

11) A 1.575 g sample of ethanedioic acid crystals, $H_2C_2O_4.nH_2O$, was dissolved in water and made up to 250 cm^3. One mole of the acid reacts with two moles of NaOH. In a titration, 25.0 cm^3 of this solution of acid reacted with exactly 15.6 cm^3 of 0.160 mol dm^{-3} NaOH. Calculate the value of n.

12) A solution of a metal carbonate, M_2CO_3, was prepared by dissolving 7.46 g of the anhydrous solid in water to give 1000 cm^3 of solution. 25.0 cm^3 of this solution reacted with 27.0 cm^3 of 0.100 mol dm^{-3} hydrochloric acid. Calculate the relative formula mass of M_2CO_3 and hence the relative atomic mass of the metal M.

13) An impure sample of barium hydroxide of mass 1.6524 g was allowed to react with 100 cm^3 of 0.200 mol dm^{-3} hydrochloric acid. When the excess acid was titrated against sodium hydroxide, 10.9 cm^3 of sodium hydroxide solution was required. 25.0 cm^3 of the sodium hydroxide required 28.5 cm^3 of the hydrochloric acid in a separate titration. Calculate the percentage purity of the sample of barium hydroxide.

2) Back titrations

A back titration is done to analyse a base (or acid) that does not react easily or quickly with an acid (or base). Instead, the base (or acid) is treated with an excess of acid (or base), and then the left over acid (or base) titrated. You can then work back to find out about the original base (or acid).

e.g. Imagine that we are trying to find out how many moles of $CaCO_3$ we have (let's call it x moles). We add 10 moles of HCl (an excess). The excess is made into a 250 cm^3 stock solution and then 25 cm^3 portions of it require 0.4 moles of NaOH for neutralisation.

$CaCO_3 + 2\,HCl \rightarrow CaCl_2 + H_2O + CO_2$ $\qquad$ $HCl + NaOH \rightarrow NaCl + H_2O$

- This means that there is 10 x 0.4 moles (= 4 moles) of left over HCl in the stock solution
- This means that 6 moles (10 – 4 moles) of HCl reacted with the $CaCO_3$.
- This means that there must have been 3 moles of $CaCO_3$ (i.e. x = 3) in the first place (remember that 2 moles of HCl reacts with each mole of $CaCO_3$).

e.g. Aspirin is a monoprotic acid that can be analysed by a back titration with NaOH. We add 0.25 moles of NaOH (an excess) to y moles of aspirin and make the resulting solution into a 250 cm^3 stock solution. We titrate 25 cm^3 portions of the solution which require 0.01 moles of HCl for neutralisation. Calculate the original moles of aspirin.

e.g. Malachite is an ore containing copper carbonate ($CuCO_3$. We add 5.00 moles of HCl (an excess) to some crushed malachite and make the resulting solution into a 250 cm^3 stock solution. We titrate 25 cm^3 portions of the solution which require 0.15 moles of NaOH for neutralisation. Calculate the original moles of copper carbonate in the malachite.

TASK 17 – BACK TITRATION CALCULATIONS

1) Limestone is mainly calcium carbonate. A student wanted to find what percentage of some limestone was calcium carbonate. A 1.00 g sample of limestone is allowed to react with 100 cm^3 of 0.200 mol dm^{-3} HCl. The excess acid required 24.8 cm^3 of 0.100 mol dm^{-3} NaOH solution in a back titration. Calculate the percentage of calcium carbonate in the limestone.

$CaCO_3 + 2\,HCl \rightarrow CaCl_2 + H_2O + CO_2$ $\qquad$ $HCl + NaOH \rightarrow NaCl + H_2O$

2) An impure sample of barium hydroxide of mass 1.6524 g was allowed to react with 100 cm^3 of 0.200 mol dm^{-3} hydrochloric acid. When the excess acid was titrated against 0.228 mol dm^{-3} sodium hydroxide in a back titration, 10.9 cm^3 of sodium hydroxide solution was required. Calculate the percentage purity of the sample of barium hydroxide.

$Ba(OH)_2 + 2\,HCl \rightarrow BaCl_2 + 2\,H_2O$ $\qquad$ $HCl + NaOH \rightarrow NaCl + H_2O$

3) Calculate (a) the moles and (b) the mass of magnesium carbonate at the start if 0.2 moles of sulfuric acid is added to the magnesium carbonate and the excess sulfuric acid made up to a 250 cm^3 solution. 25 cm^3 of this solution required 0.03 moles of sodium hydroxide for neutralisation.

$MgCO_3 + H_2SO_4 \rightarrow MgSO_4 + H_2O + CO_2$ $\qquad$ $H_2SO_4 + 2\,NaOH \rightarrow NaCl + H_2O$

4) A student wanted to find the mass of calcium carbonate in an indigestion tablet. She crushed up a tablet and added an excess of hydrochloric acid (25.0 cm^3 of 1.00 mol dm^{-3}). She then titrated the excess against 0.50 mol dm^{-3} NaOH requiring 25.8 cm^3 of the NaOH. Calculate the mass of calcium carbonate in the tablet.

5) A sample containing ammonium chloride was warmed with 100 cm^3 of 1.00 mol dm^{-3} sodium hydroxide solution. After the ammonia had reacted the excess sodium hydroxide required 50.0 cm^3 of 0.250 mol dm^{-3} HCl for neutralisation. What mass of ammonium chloride did the sample contain?

1) A fertiliser contains ammonium sulphate and potassium sulphate. A sample of 1.455 g of the fertiliser was warmed with 25 cm^3 0.2 mol dm^{-3} sodium hydroxide solution giving off ammonia gas. The remaining NaOH that was not used required 28.7 cm^3 of 0.100 mol dm^{-3} hydrochloric acid for neutralisation. Calculate the percentage by mass of ammonium sulphate in the sample.

2) Silicon tetrachloride dissolves in ethoxyethane, an inert solvent. If the ethoxyethane is contaminated with a little water, a partial hydrolysis occurs and two compounds **A** and **B** are formed. The formula of **A** is Si_2OCl_6 and that of **B** is $Si_3O_2Cl_8$.

When a 0.100 g sample of one of the compounds, **A** or **B** reacted with an excess of water, all the chlorine present was converted to chloride ions. Titration of this solution with aqueous silver nitrate, in the presence of a suitable indicator, required 42.10 cm^3 of 0.0500 mol dm^{-3} aqueous silver nitrate for complete precipitation of silver chloride. Deduce which of the compounds **A** or **B** was present in the 0.100 g sample.

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 $\therefore$ 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

$\therefore$ empirical formula = $\mathbf{Fe_3O_4}$

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

$\therefore$ empirical formula = **HO**

Formula mass of empirical formula = 17.0

$\therefore$ M_r / formula mass of empirical formula = 34.0/17.0 = 2

Molecular formula = 2 x empirical formula = $\mathbf{H_2O_2}$

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?

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TASK 1 – Writing formulas of ionic compounds

1	AgBr	2	Na_2CO_3	3	K_2O	4	Fe_2O_3	5	$CrCl_3$	6	$Ca(OH)_2$
7	$Al(NO_3)_3$	8	Na_2SO_4	9	PbO	10	Na_3PO_4	11	$Zn(HCO_3)_2$	12	$(NH_4)_2SO_4$
13	$Ga(OH)_3$	14	SrSe	15	$RaSO_4$	16	Na_3N				

TASK 2 – Writing formulas 1

1	PbO_2	2	Cu	3	Na	4	NH_4Cl	5	NH_3	6	S_8
7	H_2SO_4	8	Ne	9	SiO_2	10	Si	11	$Ba(OH)_2$	12	$SnCl_4$
13	$AgNO_3$	14	I_2	15	Ni	16	H_2S	17	TiO_2	18	Pb
19	$SrSO_4$	20	Li								

TASK 3 – Writing formulas 2

1	Ag_2CO_3	2	Au	3	PtF_2	4	HNO_3	5	NH_3	6	SiH_4
7	P_4	8	C	9	V_2O_5	10	$Co(OH)_2$	11	$Ca(OH)_2$	12	NH_4Cl
13	HCl	14	F_2	15	Si	16	$Ca_3(PO_4)_2$	17	Rb	18	GeO_2
19	$MgAt_2$	20	Ar								

TASK 4 – Writing balanced equations 1

1 a $Mg + 2\ HNO_3 \rightarrow Mg(NO_3)_2 + H_2$
b $CuCl_2 + 2\ NaOH \rightarrow Cu(OH)_2 + 2\ NaCl$
c $2\ SO_2 + O_2 \rightarrow 2\ SO_3$
d $C_4H_{10} + 6\tfrac{1}{2}\ O_2 \rightarrow 4\ CO_2 + 5\ H_2O$ or $2\ C_4H_{10} + 13\ O_2 \rightarrow 8\ CO_2 + 10\ H_2O$

2 a $4\ Na + O_2 \rightarrow 2\ Na_2O$
b $2\ Al + 3\ Cl_2 \rightarrow 2\ AlCl_3$
c $Ca + 2\ HCl \rightarrow CaCl_2 + H_2$
d $2\ NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$

TASK 5 – Writing balanced equations 2

1 $4\ Al + 3\ O_2 \rightarrow 2\ Al_2O_3$
2 $C_6H_{14} + 9\tfrac{1}{2}\ O_2 \rightarrow 6\ CO_2 + 7\ H_2O$ or $2\ C_6H_{14} + 19\ O_2 \rightarrow 12\ CO_2 + 14\ H_2O$
3 $CH_3CH_2SH + 4\tfrac{1}{2}\ O_2 \rightarrow 2\ CO_2 + SO_2 + 3\ H_2O$ or $2\ CH_3CH_2SH + 9\ O_2 \rightarrow 4\ CO_2 + 2\ SO_2 + 6\ H_2O$
4 $2\ Li + 2\ H_2O \rightarrow 2\ LiOH + H_2$
5 $CaCO_3 + 2\ HNO_3 \rightarrow Ca(NO_3)_2 + H_2O + CO_2$
6 $Li_2CO_3 \rightarrow Li_2O + CO_2$

7 $NH_3 + HNO_3 \rightarrow NH_4NO_3$
8 $K_2O + H_2SO_4 \rightarrow K_2SO_4 + H_2O$
9 $Ca(OH)_2 + 2\ HCl \rightarrow CaCl_2 + 2\ H_2O$
10 $3\ Zn + 2\ H_3PO_4 \rightarrow Zn_3(PO_4)_2 + 3\ H_2$
11 $2\ NaHCO_3 + H_2SO_4 \rightarrow Na_2SO_4 + H_2O + CO_2$
12 $2\ KOH + H_2SO_4 \rightarrow K_2SO_4 + 2\ H_2O$

TASK 6 – Ionic equations

1 HCl, LiOH, 1:1; H_2SO_4, $NaHCO_3$, 1:2; HNO_3, NH_3, 1:1; H_2SO_4, K_2CO_3, 1:1, HNO_3, $Sr(OH)_2$, 2:1

2
- a $H^+ + OH^- \rightarrow H_2O$
- b $Ag^+ + I^- \rightarrow AgI$
- c $2\ H^+ + CO_3^{2-} \rightarrow H_2O + CO_2$
- d $Ca^{2+} + 2\ OH^- \rightarrow Ca(OH)_2$
- e $NH_3 + H^+ \rightarrow NH_4^+$
- f $H^+ + HCO_3^- \rightarrow H_2O + CO_2$
- g $Ca^{2+} + SO_4^{2-} \rightarrow CaSO_4$
- h $Pb^{2+} + 2\ Cl^- \rightarrow PbCl_2$
- i $H^+ + OH^- \rightarrow H_2O$

TASK 7 – Significant figures & standard form

1	a	345800	b	297000	c	0.0790	d	6.00	e	0.00156	f	0.01000
2	a	2350000	b	0.250	c	13.7	d	30.0	e	0.00198	f	0.000313
3	a	0.0015	b	0.00046	c	357500	d	534	e	1030000	f	0.00835
4	a	1.64×10^{-4}	b	5.24×10^{-2}	c	1.5×10^{-8}	d	3.45×10^{4}	e	6.2×10^{-1}	f	8.7×10^{7}
5	a	0.0214	b	6.14×10^{-5}	c	4.00×10^{8}	d	2400	e	0.0610	f	8.00×10^{-7}

TASK 8 – Moles

1	a	2.96	b	50.3	c	0.500	d	17100	e	0.000107
2	a	355 g	b	20.4 g	c	1.08 g	d	0.264 g	e	85.8 g
3	a	0.25	b	0.25	c	0.50				
4	a	0.050	b	0.10	c	0.15				

5 176

6 a 1.670×10^{-24} g b 1.673×10^{-24} g c 5.023×10^{-24} g

TASK 9 – What equations mean

1 12 mol Na + 3 mol $O_2 \rightarrow$ 6 mol Na_2O; 0.1 mol Na + 0.025 mol $O_2 \rightarrow$ 0.05 mol Na_2O
2 5 mol Al + 7.5 mol $Cl_2 \rightarrow$ 5 mol $AlCl_3$; 0.1 mol Al + 0.15 mol $Cl_2 \rightarrow$ 0.1 mol $AlCl_3$
3 0.5 mol C_4H_{10} + 3.25 mol $O_2 \rightarrow$ 2 mol CO_2 + 2.5 mol H_2O; 20 mol C_4H_{10} + 130 mol $O_2 \rightarrow$ 80 mol CO_2 + 100 mol H_2O
4 0.5 mol NH_3 + 0.375 mol $O_2 \rightarrow$ 0.25 mol N_2 + 0.75 mol H_2O; 10 mol NH_3 + 7.5 mol $O_2 \rightarrow$ 5 mol N_2 + 15 mol H_2O

TASK 10 – Reacting mass calculations 1

1	1.01 g	2	126 g	3	120 g	4	253000 g	5	17.6 g	6	12.0 g
7	7	8	6	9	9780 g	10	1562000 g	11	0.00940 g	12	1.11 g
13	115 g	14	1650000 g	15	64.0 g	16	89.3 g				

TASK 11 – Reacting mass calculations 2

1 a 2 mol NH_3 b 6 mol NH_3 c 1.33 mol NH_3 d 1.0 mol NH_3 e 4 mol NH_3

2 a 3 mol SO_3 b 3 mol SO_3 c 0.04 mol SO_3 d 0.8 mol SO_3 e 2 mol SO_3

3 7.88 g 4 2694 g 5 303000 g 6 98.6 g 7 1210 g

8 1250 g 9 42.9 g

CHALLENGE 1

1 $NaHCO_3$ = 3.51 g, Na_2CO_3 6.49 g 2 $CaCO_3$ = 40.3%, $MgCO_3$ = 59.7% 3 C_4H_8 4 26.6%

TASK 12 – Percentage yield

1 a 120 g b 74.9% c reversible, product lost on isolation, other reactions take place

2 a 700000 g b 92.3% 3 a 510 g b 30.0%

4 a 25.2 g b 79.4% 5 a 529 g b 94.4%

6 a 330 g b 90.8% 7 a 2.40 g b 88.4%

TASK 13 – Atom economy

1 39.3% 2 1.5% 3 45.8% 4 56.0% 5 100% 6 47.1%

7 a 320 g b 87.5% c 29.5%

d % yield compares the amount produced compared to the amount you should get, atom economy is the proportion of the mass of all the products that is the desired product

TASK 14 – Ideal gas equation

1 a 473 K b 98000 Pa c 50×10^{-6} m^3 d 223 K e 100000 Pa f 3.2×10^{-3} m^3

2 1.24×10^{-3} m^3 3 0.786 4 104000 Pa 5 155 K 6 71.0 7 0.00380 m^3

8 3.36 g 9 0.000538 m^3 10 4.53 m^3 11 64.1 12 483 K 13 126400 Pa

TASK 15 – Reacting gas volumes

1 a O_2 2 dm^3, CO_2 1 dm^3 b O_2 120 cm^3, CO_2 80 cm^3

c O_2 1250 cm^3, CO_2 1000 cm^3 d O_2 5625 cm^3, CO_2 4500 cm^3q 2 20 cm^3 HBr left at end

3 300 cm^3 O_2, 100 cm^3 CO_2, total 400 cm^3 gas at end 4 4 dm^3 O_2, 4 dm^3 H_2O, 4 dm^3 SO_2, total 12 dm^3 gas

CHALLENGE 2

1 44.0 2 1 : 3.11, 40.9 g 3 NS 4 C_2H_4 5 515 ms^{-1} 6 C_3H_8

Calculations CHECK-UP

1 a $Zn(NO_3)_2$ b Pb c Cr_2O_3 d $(NH_4)_2SO_4$

e P_4 f N_2 g $Ba(OH)_2$ h $Al_2(SO_4)_3$

2 H_2SO_4, KOH, 1:2; HCl, $KHCO_3$, 1:1; HNO_3, NH_3, 1:1; HCl, $ZnCO_3$, 2:1

3 a $H^+ + OH^- \rightarrow H_2O$ b $Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4$

c $H^+ + NH_3 \rightarrow NH_4^+$ d $H^+ + HCO_3^- \rightarrow H_2O + CO_2$

4 a average mass of an atom, relative to 1/12th mass of ^{12}C atom b it is the agreed standard

c mixture of other isotopes

5 a H_2, NH_3 = 3.3.3 b H_2, NH_3 = 3.33

c N_2, NH_3 = 20 d H_2, NH_3 = 0.033

6 3.10×10^{-4} m^3 7 8.21×10^{-3}

8 a volume of CO_2 = 57.1 cm^3, total = 128.5 cm^3 b volume of CO_2 = 200 cm^3, total = 350 cm^3

c volume of CO_2 = 228.6 cm^3, total = 314.3 cm^3

9 2.00×10^{-3} m^3 10 1.64 m^3

11	a	40, 60	b	40, 20	c	5.84, 8.76					
12	193.5 g		13	9.39 g							
14	a	1250 g	b	96%	c	reversible, product lost on isolation, other reactions				d	100%
15	a	529 g	b	94.5%	c	52.9%			16	7	
17	a	0.05, 0.05, 1.22 x 10^{-3} m^3, 4.07 g					b	1.30 g, 2.77 g			

TASK 16 – Solution calculations

1	a	0.1	b	250	c	0.0025		
2	a	0.2 mol dm^{-3}, 7.3 g dm^{-3}			b	2.5 mol dm^{-3}, 245.3 g dm^{-3}	c	2.1 mol dm^{-3}, 84.0 g dm^{-3}
3	a	0.05 dm^3	b	0.001 dm^3				
4	0.0269 mol dm^{-3}, 4.61 g dm^{-3}				5	0.0752 mol dm^{-3}, 3.01 g dm^{-3}	6	0.0075 dm^3
7	0.015 mol dm^{-3}, 71.0 g dm^{-3}				8	1.13 g	9	79.9 dm^3
10	87.8				11	2	12	A_r = 39.1, K
13	90.8%							

CHALLENGE 3

1	96.7%	2	**A** Si_2OCl_6

TASK 17 – Back titration calculations

1	87.7%	2	90.8%	3	0.05 mol, 4.22 g
4	0.606 g	5	4.68 g		

TASK 18 – Empirical & molecular formulas

1	a	CH_3	b	P_2O_3	c	SO_2	d	CH_2			
	e	CH_2O	f	C_2H_7N	g	B_3H_5	h	$C_{12}H_{22}O_{11}$			
2	a	N_2H_4	b	C_4H_{10}	c	C_5H_{10}	d	PH_3	e	C_6H_6	f C_3H_6
3	a	3:2	b	1:2	c	5:1	d	2:5			
	e	3:4	f	5:3	g	4:5	h	4:7			
4	a	$CaBr_2$	b	$Na_2S_2O_3$	c	C_2H_7N	d	CO_2	e	NO_2	
5	$FeCl_3$		6	K_2SO_4	7	P_2O_3, P_4O_6	8	CH_2O, $C_2H_4O_2$			
9	$C_5H_{10}O$, $C_5H_{10}O$				10	x = 4, y = 2					

Calculation Allsorts

1	$C_5H_{11}NO$	2	$C_{11}H_{14}O_2$, $C_{11}H_{14}O_2$		3	526 g	4	2.71 g	5 5.00 dm^3
6	0.0241 mol dm^{-3}			7	234.9	8 3.21%	9	55.0%	

10 10 Al + 6 NH_4ClO_4 → 3 N_2 + 9 H_2O + 6 HCl + 5 Al_2O_3