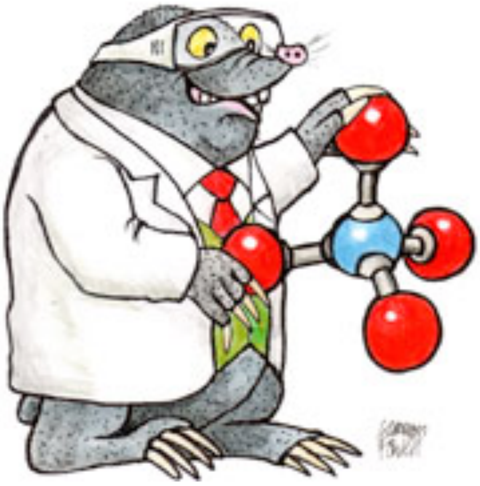
AMOUNT OF SUBSTANCE



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1 - FORMULAE

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**
He helium Ne neon Ar argon Kr krypton Xe xenon Rn radon	H_2 hydrogen N_2 nitrogen O_2 oxygen F_2 fluorine Cl_2 chlorine Br_2 bromine I_2 iodine P_4 phosphorus S_8 sulfur	There are no ionic elements!!	The formula is just the symbol, e.g. Mg magnesium Fe iron Na sodium Ni nickel	The formula is just the symbol C diamond C graphite C graphine Si silicon

Compounds

Monatomic	**Simple molecular**	**Ionic**	**Metallic**	**Giant covalent**
There are no monatomic compounds!!	Some common molecular compounds: CO_2 carbon dioxide CO carbon monoxide NO nitrogen monoxide NO_2 nitrogen dioxide SO_2 sulfur dioxide SO_3 sulfur trioxide NH_3 ammonia CH_4 methane H_2S 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: HCl hydrochloric acid H_2SO_4 sulfuric acid HNO_3 nitric acid H_3PO_4 phosphoric acid	There are no metallic compounds!!	SiO_2 silicon dioxide

Positive ions		**Negative ions**	
Group 1 ions: Li^+ lithium Na^+ sodium K^+ potassium Group 2 ions: Mg^{2+} magnesium Ca^{2+} calcium Ba^{2+} barium	Group 3 ions: Al^{3+} aluminium Other common ions Mg^{2+} silver(I) Zn^{2+} zinc(II) NH_4^+ ammonium H^+ hydrogen	Group 7 ions: $F^–$ fluoride $Cl^–$ chloride $Br^–$ bromide $I^–$ iodide Group 6 ions: $O^{2–}$ oxide $S^{2–}$ sulfide	Other common ions $NO_3^–$ nitrate $SO_4^{2–}$ sulfate $CO_3^{2–}$ carbonate $HCO_3^–$ hydrogencarbonate $OH^–$ hydroxide $H^–$ hydride $PO_4^{3–}$ phosphate

TASK 1 – WRITING FORMULAS OF IONIC COMPOUNDS

1) silver(I) 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 sulfate …………………………..
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(I) 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(I) 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 monoxide …………………………..

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 + sulfuric acid → ammonium sulfate

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 sulfuric acid

9) reaction of calcium hydroxide with hydrochloric acid

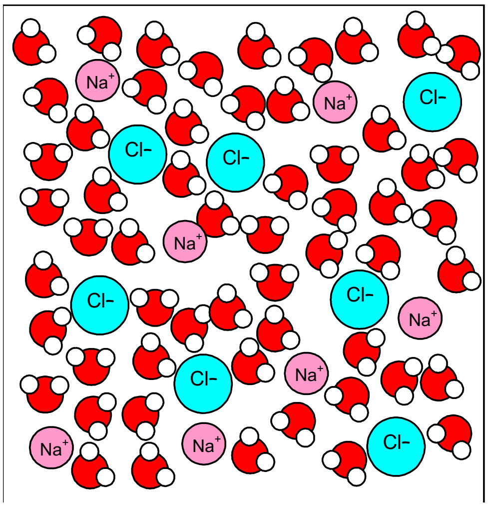
10) reaction of zinc with phosphoric acid

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.

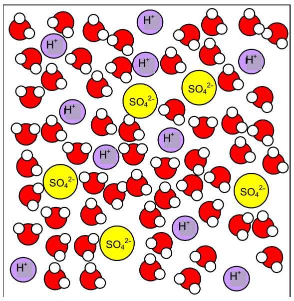
Simple examples are equations for which ionic equations can be written include:

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



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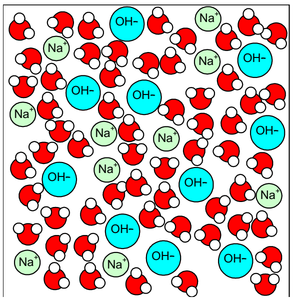

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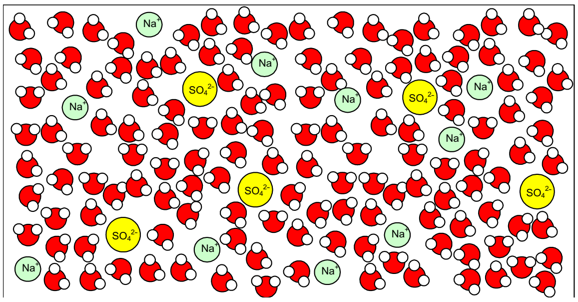


H_2SO_4 (aq)

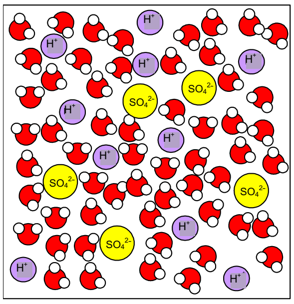
contains H^+(aq)

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



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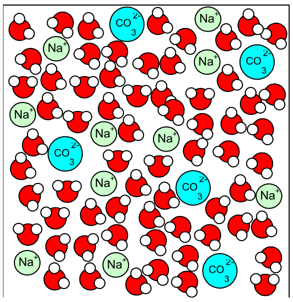

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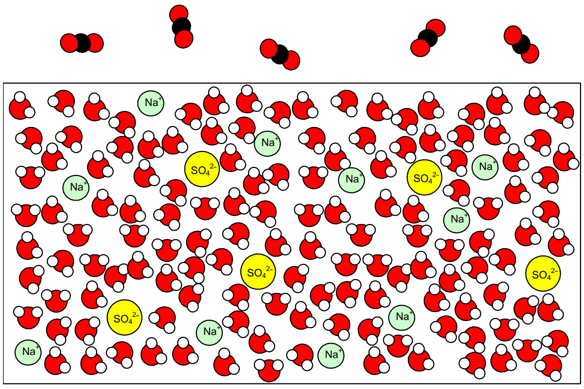


H_2SO_4 (aq)

contains H^+(aq)

Na_2CO_3 (aq)

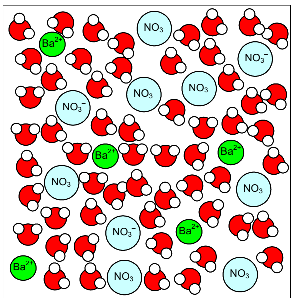
contains CO_3^{2-}(aq)

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

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.



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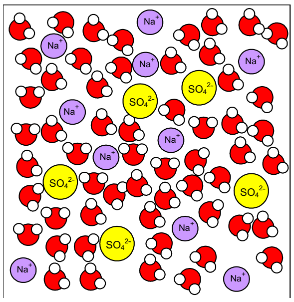

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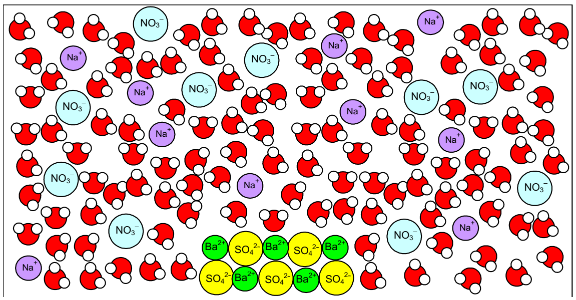
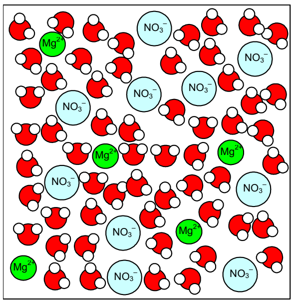


$Ba(NO_3)_2$ (aq)
contains Ba^{2+}(aq)

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.



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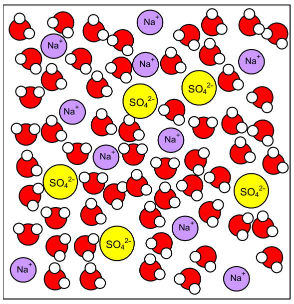

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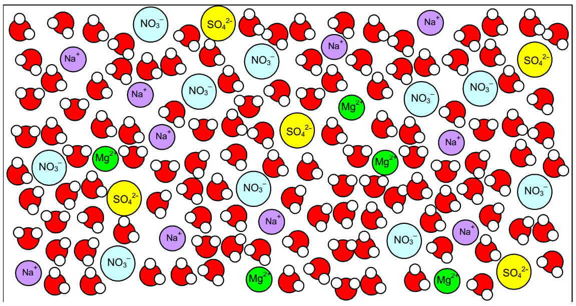


$Mg(NO_3)_2$ (aq)

Na_2SO_4 (aq)

Nothing happens – solutions just mix together (none of the combinations of ions give an insoluble compound)

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		
sulfuric acid		sodium hydrogencarbonate		
nitric acid		ammonia		
sulfuric 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(I) iodide from reaction between silver(I) 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(II) nitrate (aq) and sodium chloride (aq)

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

3 – SIGNIFICANT FIGURES & STANDARD FORM

Standard Form

- Standard form is very useful for writing very large or small numbers.
- They are written in the form A x 10^n where A is a number between 1 and 10.
- n represents the number of places the decimal point is moved (for +n values the decimal point has been moved to the left, for –n values the decimal point has been moved to the right).

Number	3435	1029000	0.025	23.2	0.0000278
Standard form	3.435 x 10^3	1.029 x 10^6	2.5 x 10^{-2}	2.32 x 10^1	2.78 x 10^{-5}

- To find the value of n:
  - for numbers greater than 1, n = number of places between first number and decimal place
  - for numbers less than 1, n = number of places from the decimal place to the first number (including that number)

Significant figures

Full number	1 sig fig	2 sig fig	3 sig fig	4 sig fig	5 sig fig
9.378652	9	9.4	9.38	9.379	9.3787
4204274	4000000	4200000	4200000	4204000	4204300
0.903521	0.9	0.90	0.904	0.9035	0.90352
0.00239482	0.002	0.0024	0.00239	0.002395	0.0023948

Significant figures for calculations involving multiplication / division

- Your final answer should be given to the same number of significant figures as the least number of significant figures in the data used.

e.g. Calculate the average speed of a car that travels 1557 m in 95 seconds.

average speed = $\frac{1557}{95}$ = 16 m s^{-1} (answer given to 2 sig fig as lowest sig figs in data is 2 sig fig for time)

e.g. Calculate the average speed of a car that travels 1557 m in 95.0 seconds.

average speed = $\frac{1557}{95}$ = 16.4 m s^{-1} (answer given to 3 sig fig as lowest sig figs in data is 3 sig fig for time)

Significant figures for calculations involving addition/subtraction ONLY

- Here the number of significant figures is irrelevant – it is about the place value of the data. For example

e.g. Calculate the total energy released when 263 kJ and 1282 kJ of energy are released.

Energy released = 263 + 1282 = 1545 kJ (answer is to nearest unit as both values are to nearest unit)

e.g. Calculate the total mass of calcium carbonate when 0.154 g and 0.01234 g are mixed.

Mass = 0.154 + 0.01234 = 0.166 g (answer is to nearest 0.001 g as least precise number is to nearest 0.001 g)

TASK 7 – SIGNIFICANT FIGURES & STANDARD FORM

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

a) 345789 4 sig figs ………………… d) 6.0961 3 sig figs ………………….
b) 297300 3 sig figs ………………… e) 0.001563 3 sig figs ………………….
c) 0.07896 3 sig figs ………………… f) 0.010398 4 sig figs ………………….

2) Complete the following sums and give the answers to the appropriate number of significant figures.

a) 6125 x 384 ………………… d) 7550 ÷ 25 ………………….
b) 25.00 x 0.010 ………………… e) 0.000152 x 13.00 ………………….
c) 13.5 + 0.18 ………………… f) 0.0125 x 0.025 ………………….

3) Write the following numbers in non standard form.

a) 1.5 x 10^{-3} ………………….. d) 5.34 x 10^{2} ……………………
b) 4.6 x 10^{-4} …………………..... e) 1.03 x 10^{6} ……………………
c) 3.575 x 10^{5} …………………..... f) 8.35 x 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 the appropriate number of significant figures.

a) 6.125 x 10^{-3} x 3.5 …………………………………………………………..
b) 4.3 x 10^{-4} ÷ 7.00 …………………………………………………………..
c) 4.0 x 10^{8} + 35000 ……………..
d) 0.00156 + 2.4 x 10^{3} ………………………………………………………….
e) 6.10 x 10^{-2} – 3.4 x 10^{-5} ………………………………………………………….
f) 8.00 x 10^{-3} x 0.100 x 10^{-3} ………………………………………………………….

4 – RELATIVE MASS

- Most elements are made of up atoms of different isotopes (e.g. chlorine contains both ^{35}Cl and ^{37}Cl atoms)
- The relative atomic mass (A_r) of an element is an average of the mass of the isotopes taking into account the relative abundance of each isotope.

Relative atomic mass, A_r	Average mass of an atom of an element relative to $\frac{1}{12}$th the mass of ^{12}C atom
Relative formula mass, M_r	*If referring specifically to a molecule (relative molecular mass)* Average mass of a molecule of a substance relative to $\frac{1}{12}$th the mass of ^{12}C atom
	More generally for any substance Sum of the relative atomic masses of all the atoms in the formula of a substance

TASK 8 – RELATIVE FORMULA MASS

Calculate the M_r of each of these substances.

1 F_2 ……………………………………………………………………………………………..

2 Fe ……………………………………………………………………………………………..

3 H_2SO_4 ……………………………………………………………………………………………..

4 Al_2O_3 ……………………………………………………………………………………………..

5 $Mg(OH)_2$ ……………………………………………………………………………………………..

6 $Al(NO_3)_3$ ……………………………………………………………………………………………..

7 $(NH_4)_2SO_4$ ……………………………………………………………………………………………..

8 $CuCO_3$ ……………………………………………………………………………………………..

9 $AgNO_3$ ……………………………………………………………………………………………

10 NH_4NO_3 ……………………………………………………………………………………………..

11 $CuSO_4.5H_2O$ ……………………………………………………………………………………………..

12 magnesium ………………………………………………………………………………………………..

13 oxygen ……………………………………………………………………………………………..

14 sodium bromide …………………………………………………………………………………………..

15 calcium fluoride ………………………………………………………………………………………

16 potassium sulfate …………………………………………………………………………………………..

17 chlorine …………………………………………………………………………………………..

18 iron(III) sulfate …………………………………………………………………………………………..

5 – THE MOLE & AVOGADRO CONSTANT

- One mole of anything contains 6.022 x 10^{23} of those things. One mole of bananas is 6.022 x 10^{23} bananas. One mole of water molecules is 6.022 x 10^{23} water molecules
- This number is known as the Avogadro constant (= 6.022 x 10^{23} mol^{-1}).
- 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.

$$\textbf{Moles} = \frac{\textbf{mass (g)}}{M_r}$$

1 ton = 1,000,000 g

1 kg = 1,000 g

1 mg = 0.001 g

Remember *Mr Moles!*

TASK 9 – MOLES

1) How many moles are there in each of the following?
   - a) 72.0 g of Mg
   - b) 4.00 kg of CuO
   - c) 39.0 g of $Al(OH)_3$
   - d) 1.00 tonne of NaCl
   - e) 20.0 mg of $Cu(NO_3)_2$

2) What is the mass of each of the following?
   - a) 5.00 moles of Cl_2
   - b) 0.200 moles of Al_2O_3
   - c) 0.0100 moles of Ag
   - d) 0.00200 moles of $(NH_4)_2SO_4$
   - e) 0.300 moles of $Na_2CO_3.10H_2O$

3) a) Calculate the number of moles of CO_2 molecules in 11.0 g of carbon dioxide.
   b) Calculate the number of moles of C atoms in 11.0 g of carbon dioxide.
   a) Calculate the number of moles of O atoms in 11.0 g of carbon dioxide.

4) a) Calculate the number of moles of Al_2O_3 in 5.10 g of Al_2O_3
   b) Calculate the number of moles of Al^{3+} ions in 5.10 g of Al_2O_3
   a) Calculate the number of moles of O^{2-} ions in 5.10 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 1.00 g contains 0.00568 moles of Vitamin C molecules. Calculate the M_r of vitamin C.

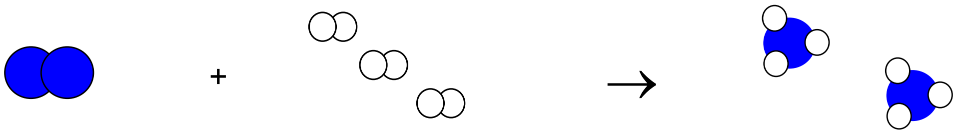
6) Use the following data to calculate the mass of the particles shown.

   Mass of proton = 1.6726 x 10^{-24} g
   Mass of electron = 9.1094 x 10^{-28} g
   Mass of neutron = 1.6749 x 10^{-24} g
   Avogadro constant = 6.022 x 10^{23} mol^{-1}

   a) Calculate the mass of a ^{1}H atom.
   b) Calculate the mass of an $^{1}H^{+}$ ion.
   c) Calculate the mass of one mole of ^{3}H atoms.

6 – 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
12 molecule 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 x 10^{23} molecule N_2 1 moles N_2		18 x 10^{23} molecules H_2 3 moles H_2		12 x 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 10 – 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 32.0 kg of iron(III) oxide is heated with CO?

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

moles of Fe_2O_3 = $\frac{\text{mass (g)}}{M_r}$ = $\frac{32000}{159.6}$ = 200.5 mol

1 mole of Fe_2O_3 forms 2 moles of Fe

∴ moles of Fe = 2 x 200.5 = 401.0 mol

∴ 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?

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

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 ∴ 1 mole of NH_3 reacts with ¾ mole of O_2

∴ moles of O_2 = 6.00 x ¾ = 4.50 mol

∴ 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

∴ moles of $SnCl_2.xH_2O$ = 0.02214 mol

∴ M_r of $SnCl_2.xH_2O$ = $\frac{\text{mass (g)}}{\text{moles}}$ = $\frac{5.00}{0.02214}$ = 225.8

∴ M_r of xH_2O = 225.8 – 189.7 = 36.1

∴ x = $\frac{36.1}{18.0}$ = **2** (x is a whole number and so the final answer is given as an integer)

TASK 11 – REACTING MASS CALCULATIONS 1

1) What mass of hydrogen is needed to react with 40.0 g of copper(II) 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 96.0 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(III) oxide?

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

5) What mass of carbon dioxide is produced when 5.60 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 8.50 g of hydrogen sulfide (H_2S)?

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

7) 4.92 g of hydrated magnesium sulfate crystals ($MgSO_4.nH_2O$) gave 2.40 g of anhydrous magnesium sulfate on heating to constant mass. Work out the formula mass of the hydrated magnesium sulfate 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 1.000 tonnes 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 7.80 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. Propane reacts with oxygen as shown: $C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$

How many moles of products are formed when 1 mole of C_3H_8 is mixed with 8 moles of O_2?

	C_3H_8	+	$5\ O_2$	$\rightarrow$	$3\ CO_2$	+	$4\ H_2O$
moles at the start	1 mol		8 mol				
change in moles	1 mol react		5 mol react		3 mol made		4 mol made
moles at the end	1 – 1 = 0 mol		8 – 5 = 3 mol		0 + 3 = 3 mol		0 + 4 = 4 mol
	C_3H_8 limiting reagent		O_2 in excess				

e.g. Sulfur dioxide reacts with oxygen as shown: $2\ SO_2 + O_2 \rightarrow 2\ SO_3$

How many moles of SO_3 are formed when 5 mole of SO_2 is mixed with 2 moles of O_2?

	$2\ SO_2$	+	O_2	$\rightarrow$	$2\ SO_3$
moles at the start	5 mol		2 mol		
change in moles	4 mol react		2 mol react		4 mol made
moles at the end	5 – 4 = 1 mol		2 – 2 = 0 mol		0 + 4 = 4 mol
	SO_2 in excess		O_2 limiting reagent		

- In calculations you will be asked to work with masses, but you will need to convert to moles to find out which is the limiting reagent in order to work out the required answer.

e.g. In the manufacture of titanium, what mass of titanium can theoretically be formed when 1.00 kg of titanium chloride reacts with 0.100 kg of magnesium?

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

	$TiCl_4$	+	$2\ Mg$	$\rightarrow$	**Ti**	+	$2\ MgCl_2$
moles at the start	$\frac{1000}{189.9}$ = 5.266 mol		$\frac{100}{24.3}$ = 4.115 mol				

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

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

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

change in moles	– 2.058 mol	– 4.115 mol	+ 2.058	+ 4.115 mol
moles at the end			0 + 2.058 = 2.058 mol	

∴ Mass of Ti = 2.058 x M_r = 2.058 x 47.9 = 98.6 g

TASK 12A – LIMITING REAGENTS 1

1		**CaO**	**+**	**H_2O**	→	**$Ca(OH)_2$**		
	a)	2 mol		3 mol				
	b)	10 mol		8 mol				
	c)	0.40 mol		0.50 mol				
2		**2Ca**	**+**	**O_2**	→	**2CaO**		
	a)	2 mol		2 mol				
	b)	10 mol		2 mol				
	c)	0.50 mol		0.20 mol				
3		**2Fe**	**+**	**$3Cl_2$**	→	**$2FeCl_3$**		
	a)	3 mol		3 mol				
	b)	12 mol		15 mol				
	c)	20 mol		40 mol				
4		**$TiCl_4$**	**+**	**4Na**	→	**Ti**	**+**	**4NaCl**
	a)	4 mol		4 mol				
	b)	2 mol		10 mol				
	c)	0.5 mol		1 mol				
5		**C_2H_5OH**	**+**	**$3O_2$**	→	**$2CO_2$**	**+**	**$3H_2O$**
	a)	15 mol		30 mol				
	b)	0.25 mol		1 mol				
	c)	3 mol		6 mol				
6		**N_2**	**+**	**$3H_2$**	→	**$2NH_3$**		
	a)	3 mol		6 mol				
	b)	0.5 mol		0.9 mol				
	c)	6 mol		20 mol				
7		**4K**	**+**	**O_2**	→	**$2K_2O$**		
	a)	10 mol		2 mol				
	b)	6 mol		4 mol				
	c)	0.50 mol		0.20 mol				

TASK 12B – LIMITING REAGENTS 2

1	What mass of calcium hydroxide is formed when 10.0 g of calcium oxide reacts with 10.0 g of water?	$CaO + H_2O \rightarrow Ca(OH)_2$
2	What mass of magnesium bromide is formed when 1.00 g of magnesium reacts with 5.00 g of bromine?	$Mg + Br_2 \rightarrow MgBr_2$
3	What mass of copper is formed when 2.00 g of copper(II) oxide reacts with 1.00 g of hydrogen?	$CuO + H_2 \rightarrow Cu + H_2O$
4	What mass of sodium fluoride is formed when 2.30 g of sodium reacts with 2.85 g of fluorine?	$2Na + F_2 \rightarrow 2NaF$
5	What mass of iron is formed when 8.00 g of iron(III) oxide reacts with 2.16 g of aluminium?	$Fe_2O_3 + 2Al \rightarrow 2Fe + Al_2O_3$
6	What mass of aluminium chloride is formed when 13.5 g of aluminium reacts with 42.6 g of chlorine?	$2Al + 3Cl_2 \rightarrow 2AlCl_3$

TASK 12C – REACTING MASS CALCULATIONS 2

1) 5.00 g of iron and 5.00 g of sulfur are heated together to form iron(II) sulfide. Which reactant is in excess and what is the maximum mass of iron(II) sulfide that can be formed?

   $Fe + S \rightarrow FeS$

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

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

3) In the Solvay process, ammonia is recovered by the reaction shown. What is the maximum mass of ammonia that can be recovered from 2.00 tonnes of ammonium chloride and 0.500 tonnes of calcium oxide?

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

4) In the manufacture of titanium, what mass of titanium can theoretically be formed when 0.500 kg of titanium chloride reacts with 0.100 kg of magnesium?

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

5) In the manufacture of ammonia, what mass of ammonia can theoretically be formed when 1.00 kg of nitrogen reacts with 0.500 kg of hydrogen?

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

6) In the manufacture of sulfur trioxide, what mass of sulfur trioxide can theoretically be formed when 1.00 kg of sulfur dioxide reacts with 0.500 kg of oxygen?

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

7) 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(I). What mass of hydrazine is made by reaction of 100 g of ammonia with 100 g of sodium chlorate(I)?

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

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.

Percentage 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.

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

e.g. Tungsten is made from tungsten(VI) oxide: $WO_3 + 3\,H_2 \rightarrow W + 3\,H_2O$

a) Calculate the maximum theoretical mass of tungsten that can be made from 0.500 tonne of tungsten(VI) oxide.

$$\text{Moles of } WO_3 = \frac{\text{mass (g)}}{M_r} = \frac{500000}{231.8} = 2157 \text{ mol}$$

∴ moles of W = 2157 mol

∴ mass of W = moles x M_r = 2157 x 183.8 = **396000 g** (3 sig fig)

b) In the reaction, only 350000 g of tungsten was made. Calculate the percentage yield.

$$\% \text{ Yield} =. \frac{\text{mass of product obtained}}{\text{maximum theoretical mass of product}}\ x\ 100 = \frac{350000}{396000}\ x\ 100 = \mathbf{88.3\%} \text{ (3 sig fig)}$$

TASK 13 – 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 96.0 g of sulfur dioxide with an excess of oxygen.

   b) In the reaction, only 90.0 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(III) 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 1.00 tonne of iron(III) oxide.

   b) In the reaction, only 650000 g of iron (to 3 significant figures) 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 90.0 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 20.0 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 1.00 kg of aluminium oxide.

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

6) The fertiliser ammonium sulfate 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 85.0 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.

$$\% \text{ atom economy} = \frac{\text{mass of desired product as shown in equation}}{\text{total mass of products as shown in equation}} x\ 100$$

e.g. *making ethanol by fermentation*

glucose → ethanol + carbon dioxide

$$\underset{180\text{ g}}{C_6H_{12}O_6(aq)} \rightarrow \underbrace{\underset{92\text{ g}}{2\ CH_3CH_2OH(aq)} + \underset{88\text{ g}}{2\ CO_2}}_{180\text{ g products}}$$

Atom economy = $\frac{92}{180} x\ 100$ = 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 14 – ATOM ECONOMY

1)	Calculate the percentage atom economy to make sodium from sodium chloride.	$2\ NaCl \rightarrow 2\ Na + Cl_2$
2)	Calculate the percentage atom economy to make hydrogen from the reaction of zinc with hydrochloric acid.	$Zn + 2\ HCl \rightarrow ZnCl_2 + H_2$
3)	Calculate the percentage atom economy to make iron from iron(III) oxide in the Blast Furnace.	$Fe_2O_3 + 3\ CO \rightarrow 2\ Fe + 3\ CO_2$
4)	Calculate the percentage atom economy to make calcium oxide from calcium carbonate.	$CaCO_3 \rightarrow CaO + CO_2$
5)	Calculate the percentage atom economy to make sulfur trioxide from sulfur dioxide.	$2\ SO_2 + O_2 \rightarrow 2\ SO_3$
6)	Calculate the percentage 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(I) (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 percentage atom economy for this way of making hydrazine.

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

7 – 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 $\therefore \frac{M_r}{M_r \text{ of empirical formula}} = \frac{42.0}{14.0} = 3$

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 $\frac{72.4}{55.8} = 1.30$ O $\frac{27.6}{16.0} = 1.73$

Simplest ratio Fe:O = 1.30 : 1.73 (divide by smallest, i.e. 1.29)

$\frac{1.30}{1.30} : \frac{1.73}{1.30}$

1 : 1.33 (involves $^1/_3$'s so x3)

3 : 4

$\therefore$ 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 $\frac{0.25}{1.0} = 0.25$ O $\frac{4.00}{16.0} = 0.25$

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

$\therefore \frac{M_r}{M_r \text{ of empirical formula}} = \frac{34.0}{17.0} = 2$

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

TASK 15 – EMPRICIAL & MOLECULAR FORMULAS

1) The molecular formula of some substances are shown. Write the empirical formula of each substance.

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 $M_r = 32.0$ d) PH_3 $M_r = 34.0$

b) C_2H_5 $M_r = 58.0$ e) CH $M_r = 78.0$

c) CH_2 $M_r = 70.0$ f) CH_2 $M_r = 42.0$

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 sulfur, 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.

8 – GAS CALCULATIONS

THE IDEAL GAS EQUATION

- In order to perform calculations with gases we assume that they behave like an ideal gas (i.e. there are no forces between particles, the size of their particles is negligible, etc.).
- While real gases are not ideal gases (e.g. there are weak forces between particles), treating them like an ideal gas is a very good approximation in calculations and so we use the ideal gas law for all gases.

$$\boxed{PV = nRT}$$

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***
$dm^3 \times 10^{-3} = m^3$	$cm^3 \times 10^{-6} = m^3$	$kPa \times 10^3 = Pa$	$MPa \times 10^6 = Pa$	°C + 273 = K

e.g. Calculate the pressure exerted by 0.100 moles of an ideal gas at 50.0°C with a volume of 1500 cm^3

$$P = \frac{nRT}{V} = \frac{0.100\ x\ 8.31\ x\ 323}{1500 \times 10^{-6}} = 179000\ Pa\ (3sf)$$

TASK 16 – 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 (3sf) and a pressure of 1000 kPa (4sf).

3) How many moles of gas occupy 19400 cm^3 at 27.0ºC and 101 kPa pressure?

4) Calculate the pressure that 0.0500 moles of gas, which occupies a volume of 200 cm^3 (3sf) exerts at a temperature of 50.0 K.

5) 0.140 moles of a gas has a volume of 2.00 dm^3 at a pressure of 90.0 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 20.0ºC and 100 kPa (3sf).

$$CaC_2(s) + 2\ H_2O(l) \rightarrow Ca(OH)_2(aq) + C_2H_2(g)$$

8) What mass of potassium chlorate(V) must be heated to give 1.00 dm^3 of oxygen at 20.0ºC and 0.100 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?

$$2\ Na(s) + 2\ H_2O(l) \rightarrow 2\ NaOH(aq) + H_2(g)$$

10) What volume of carbon dioxide gas, measured at 800 K and 100 kPa, is formed when 1.00 kg of propane is burned in a good supply of oxygen?

$$C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$$

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 25.0ºC 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 (3sf) and 8.70 x 10^4 Pa. At what temperature will it occupy 3.95 dm^3 at 1.01 x 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 17 – 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 sulfide 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 1.01×10^5 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 60.0 dm^3 air bag at room temperature and atmospheric pressure.

3) 1.00 g of sulfur dissolved completely in an excess of liquid ammonia to give 420 cm^3 of hydrogen sulfide (H_2S), measured at 273 K and 101 kPa, and also a solid containing the elements nitrogen and sulfur. 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 excess), the final volume was 45 cm^3. This decreased to 15 cm^3 on treatment with NaOH solution (which removes CO_2). What was the formula of the hydrocarbon? (all measurements were made at room temperature and pressure, $\therefore$ 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.

Should I get a Health Checkup?

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

a) zinc(II) nitrate …………………

b) lead …………………

c) chromium(III) oxide …………………

d) ammonium sulfate …………………

e) phosphorus ………………………

f) nitrogen ………………………

g) barium hydroxide ………………………

h) aluminium sulfate ……………………… (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
sulfuric 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 sulfuric 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 sulfuric 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) 5.00 moles of N_2 + 5.00 moles of H_2 moles of NH_3 formed = ………….. (1)

b) 2.00 moles of N_2 + 5.00 moles of H_2 moles of NH_3 formed = ………….. (1)

c) 10.0 moles of N_2 + 50.0 moles of H_2 moles of NH_3 formed = ………….. (1)

d) 0.200 moles of N_2 + 0.0500 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 2.00 MPa pressure.

……

……

……

…… (3)

7) Calculate the number of moles of argon in 200 cm^3 (3sf) at 100 kPa (3sf) at 20.0°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 20.0°C and 100000 Pa (3sf) pressure when 2.00 g of magnesium is reacted with excess sulfuric 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 0.140 MPa pressure when 1.00 kg of iron(III) 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 1.00 kg of aluminium sulfate

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

ii) how many moles of sulfate 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 7.80 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 1.00 kg of sulfur dioxide.

$$2\ SO_2 + O_2 \text{ — } 2\ SO_3$$

………

………

……… (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 1.00 kg of aluminium oxide.

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

………

………

……… (3)

b) Calculate the percentage yield if 500 g (3sf) of aluminium is produced.

……… (1)

c) Calculate the percentage atom economy for this process.

……… (1)

16) When 12.30 g of $MgSO_4.nH_2O$ is heated gently until no further change in mass occurs, to remove the water of crystallisation, 6.00 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 0.900 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 0.0320 moles of $H^+(aq)$. The equation for the reaction between zinc(II) oxide and acid is:

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

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

……….. (2)

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

………..

……….. (2)

9 – SOLUTION CALCULATIONS

$$\text{concentration} = \frac{\text{moles}}{\text{volume (dm}^3\text{)}}$$

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

b) Use the balanced (or ionic) equation to find the moles of the other reactant.

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

Note

- Volume in dm^3 = $\frac{\text{volume in cm}^3}{1000}$ (e.g. 25 cm^3 → $\frac{25}{1000}$ = 0.025 dm^3)
- Concentration in g dm^{-3} = **concentration in mol dm^{-3} x M_r** (e.g. H_2SO_4 0.10 mol dm^{-3} → 0.10 x 98 dm^3 = 9.8 g dm^{-3})
- 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.

type of acid	what it means	examples	reacting ratio with NaOH
monoprotic	one H^+ ion per unit	HCl, HNO_3, CH_3COOH	1 : 1 (acid : NaOH)
diprotic	two H^+ ions per unit	H_2SO_4	1 : 2 (acid : NaOH)
triprotic	three H^+ ions per unit	H_3PO_4	1 : 3 (acid : NaOH)

E.g. 1: 25.0 cm^3 of 0.020 mol dm^{-3} sulfuric 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) = $0.020\,x\,\frac{25.0}{1000}$ = 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 = $\frac{\text{moles}}{\text{volume (dm}^3\text{)}}$ = $\frac{0.00100}{\frac{18.6}{1000}}$ = **0.0538 mol dm^{-3}**

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 = **2.15 g dm^{-3}**

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} sodium hydroxide for neutralisation. Calculate the M_r and the value of n.

Moles of NaOH = conc x vol (dm^3) = $0.100\,x\,\frac{21.80}{1000}$ = 0.00218

Moles of $C_6H_8O_7.nH_2O$ in each titration = $\frac{0.00218}{3}$ = 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 $C_6H_8O_7.nH_2O$ = $\underline{\text{mass}}$ = $\frac{1.52}{0.00727}$ = **209.2**

M_r of nH_2O = 209.2 – 192.0 = 17.0 n = $\frac{17.0}{18.0}$ = 0.954 = **1 (n is a whole number)**

TASK 18 – 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} sulfuric 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.

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).

As an alternative, 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 *p* moles). We add 10 moles of HCl (an excess). The excess is made into a 250 cm^3 solution in a volumetric flask 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 volumetric flask solution (as we used 1/10th of the solution in the volumetric flask in each titration)
- 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. *p* = 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 19 – 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 0.200 moles of sulfuric acid is added to the magnesium carbonate and the excess sulfuric acid made up to a 250 cm^3 solution. 25.0 cm^3 of this solution required 0.0300 moles of sodium hydroxide for neutralisation.

$MgCO_3 + H_2SO_4 \rightarrow MgSO_4 + H_2O + CO_2$ $\qquad$ $H_2SO_4 + 2\,NaOH \rightarrow Na_2SO_4 + 2\,H_2O$

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 0.500 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 sulfate and potassium sulfate. A sample of 1.455 g of the fertiliser was warmed with 25.0 cm^3 0.200 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 sulfate 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(I) nitrate, in the presence of a suitable indicator, required 42.10 cm^3 of 0.0500 mol dm^{-3} aqueous silver(I) nitrate for complete precipitation of silver(I) chloride. Deduce which of the compounds **A** or **B** was present in the 0.100 g sample.

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(III) 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 sulfuric acid in a titration. Find the concentration of the sulfuric acid.

7) 13.80 g of a solid monoprotic acid was dissolved in water and made up to 250.0 cm^3. 25.00 cm^3 portions of this were titrated against 0.2500 mol dm^{-3} sodium hydroxide, requiring 23.50 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	$Ba(OH)_2$	12	NH_3
13	HCl	14	F_2	15	Si	16	$Ca_3(PO_4)_2$	17	Rb	18	GeO_2
19	$MgAt_2$	20	NO								

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 $C_4H_{10} + 6\frac{1}{2}\ O_2 \rightarrow 4\ CO_2 + 5\ H_2O$ 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 $C_6H_{14} + 9\frac{1}{2}\ O_2 \rightarrow 6\ CO_2 + 7\ H_2O$ or $2\ C_6H_{14} + 19\ O_2 \rightarrow 12\ CO_2 + 14\ H_2O$

3 $CH_3CH_2SH + 4\frac{1}{2}\ O_2 \rightarrow 2\ CO_2 + SO_2 + 3\ H_2O$ 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 $2\ NaHCO_3 + H_2SO_4 \rightarrow Na_2SO_4 + 2\ H_2O + 2\ CO_2$
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 6.10	e 0.00156	f 0.01040
2	a 2350000 (3sf)	b 0.25 (2sf)	c 13.7	d 300 (2sf)	e 0.00198 (3sf)	f 0.00031 (2sf)
3	a 0.0015	b 0.00046	c 357500	d 534	e 1030000	f 0.00835
4	a 1.64 x 10^{-4}	b 5.24 x 10^{-2}	c 1.5 x 10^{-8}	d 3.45 x 10^{4}	e 6.2 x 10^{-1}	f 8.7 x 10^{7}
5	a 0.021 (2sf)	b 6.1 x 10^{-5} (2sf)	c 4.0 x 10^{8}	d 2400	e 0.0610	f 8.00 x 10^{-7} (3sf)

TASK 8 – Relative formula mass

1	38.0	2	55.8	3	98.1	4	102.0	5	58.3	6	213.0
7	132.1	8	123.5	9	169.9	10	80.0	11	249.5	12	24.3
13	32.0	14	102.9	15	78.1	16	174.3	17	71.0	18	399.9

TASK 9 – 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	0.250	b	0.250	c	0.500				
4	a	0.0500	b	0.100	c	0.150				
5	176									
6	a	1.6735 x 10^{-24} g	b	1.6726 x 10^{-24} g	c	3.025 g				

TASK 10 – 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 11 – Reacting mass calculations 1

1	1.0 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	1560000 g	11	0.00940 g	12	1.11 g
13	115 g	14	1650000 g	15	64.0 g	16	89.3 g				

TASK 12A – Limiting reagents 1

1 a 2 mol b 8 mol c 0.4 mol
2 a 2 mol b 4 mol c 0.4 mol
3 a 2 mol b 10 mol c 20 mol
4 a 1, 4 mol b 2, 8 mol c 0.25, 1 mol
5 a 20, 30 mol b 0.5, 0.75 mol c 4, 6 mol
6 4 mol b 0.6 mol c 12 mol
7 4 mol b 3 mol c 0.25 mol

TASK 12B – Limiting reagents 2

1 13.2 g 2 5.75 g 3 1.60 g 4 4.20 g 5 4.48 g
6 53.4 g

TASK 12C – Reacting mass calculations 2

1 7.88 g 2 2690 g 3 303000 g 4 98.6 g 5 1210 g
6 1250 g 7 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 13 – Percentage yield

1 a 120 g b 74.9% c reversible, product lost on isolation, other reactions take place
2 a 701000 g b 92.7% 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 14 – 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 15 – 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

TASK 16 – 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 126000 Pa

TASK 17 – 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 3.21 : 1, 130.5 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 = 3.33 b H_2, NH_3 = 3.33
c N_2, NH_3 = 20.0 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 = 229 cm^3, total = 314 cm^3
9 2.00×10^{-3} m^3 10 1.64 m^3
11 a 40, 60 b 40.0, 20.0 c 5.84, 8.76
12 193.5 g 13 9.39 g
14 a 1250 g b i 96% ii reversible, product lost on isolation, other reactions iii 100%
15 a 529 g b 94.5% c 52.9% 16 7
17 a 0.05, 0.05, 1.22×10^{-3} m^3, 4.07 g b 1.30 g, 2.77 g

TASK 18 – 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 0.0512 mol dm^{-3}, 2.10 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 0.0500 mol dm^{-3}, 7.10 g dm^{-3} 8 1.13 g 9 79.9 dm^3
10 87.8 11 2 12 A_r = 39.1, K

CHALLENGE 3

1 9.67% 2 **A** Si_2OCl_6

TASK 19 – Back titration calculations

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

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 $10\ Al + 6\ NH_4ClO_4 \rightarrow 3\ N_2 + 9\ H_2O + 6\ HCl + 5\ Al_2O_3$