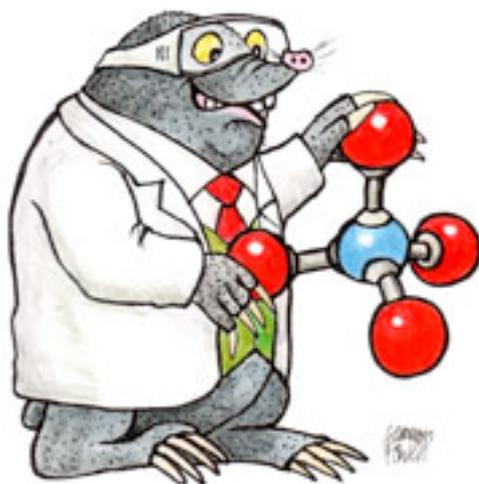


# AMOUNT OF SUBSTANCE



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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	H <sub>2</sub> hydrogen	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
Ne neon	N <sub>2</sub> nitrogen			
Ar argon	O <sub>2</sub> oxygen			
Kr krypton	F <sub>2</sub> fluorine			
Xe xenon	Cl <sub>2</sub> chlorine			
Rn radon	Br <sub>2</sub> bromine			
	I <sub>2</sub> iodine			
	P <sub>4</sub> phosphorus			
	S <sub>8</sub> sulfur			

## Compounds

Monatomic	Simple molecular	Ionic	Metallic	Giant covalent
There are no monatomic compounds!!	Some common molecular compounds: CO <sub>2</sub> carbon dioxide CO carbon monoxide NO nitrogen monoxide NO <sub>2</sub> nitrogen dioxide SO <sub>2</sub> sulfur dioxide SO <sub>3</sub> sulfur trioxide NH <sub>3</sub> ammonia CH <sub>4</sub> methane H <sub>2</sub> S 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 <sub>2</sub> SO <sub>4</sub> sulfuric acid HNO <sub>3</sub> nitric acid H <sub>3</sub> PO <sub>4</sub> phosphoric acid	There are no metallic compounds!!	SiO <sub>2</sub> silicon dioxide

Positive ions		Negative ions	
Group 1 ions: Li <sup>+</sup> lithium Na <sup>+</sup> sodium K <sup>+</sup> potassium	Group 3 ions: Al <sup>3+</sup> aluminium	Group 7 ions: F <sup>-</sup> fluoride Cl <sup>-</sup> chloride Br <sup>-</sup> bromide I <sup>-</sup> iodide	Other common ions NO <sub>3</sub> <sup>-</sup> nitrate SO <sub>4</sub> <sup>2-</sup> sulfate CO <sub>3</sub> <sup>2-</sup> carbonate HCO <sub>3</sub> <sup>-</sup> hydrogencarbonate
Group 2 ions: Mg <sup>2+</sup> magnesium Ca <sup>2+</sup> calcium Ba <sup>2+</sup> barium	Other common ions Mg <sup>2+</sup> silver(I) Zn <sup>2+</sup> zinc(II) NH <sub>4</sub> <sup>+</sup> ammonium H <sup>+</sup> hydrogen	Group 6 ions: O <sup>2-</sup> oxide S <sup>2-</sup> sulfide	OH <sup>-</sup> hydroxide H <sup>-</sup> hydride PO <sub>4</sub> <sup>3-</sup> phosphate

## **TASK 1 – WRITING FORMULAS OF IONIC COMPOUNDS**

- |                                 |                                  |
|---------------------------------|----------------------------------|
| 1) silver(I) bromide .....      | 9) lead(II) oxide .....          |
| 2) sodium carbonate .....       | 10) sodium phosphate .....       |
| 3) potassium oxide .....        | 11) zinc hydrogencarbonate ..... |
| 4) iron(III) oxide .....        | 12) ammonium sulfate .....       |
| 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(I) 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(I) 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 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	$2 \text{Mg} + \text{O}_2 \rightarrow 2 \text{MgO}$ $2 \text{H}_2\text{S} + 3 \text{O}_2 \rightarrow 2 \text{H}_2\text{O} + 2 \text{SO}_2$ $\text{C}_3\text{H}_8 + 5 \text{O}_2 \rightarrow 3 \text{CO}_2 + 4 \text{H}_2\text{O}$
metal + water → metal hydroxide + hydrogen	$2 \text{Na} + 2 \text{H}_2\text{O} \rightarrow 2 \text{NaOH} + \text{H}_2$
metal + acid → salt + hydrogen	$\text{Mg} + 2 \text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2$
oxide + acid → salt + water	$\text{MgO} + 2 \text{HNO}_3 \rightarrow \text{Mg}(\text{NO}_3)_2 + \text{H}_2\text{O}$
hydroxide + acid → salt + water	$2 \text{NaOH} + \text{H}_2\text{SO}_4 \rightarrow \text{Na}_2\text{SO}_4 + \text{H}_2\text{O}$
carbonate + acid → salt + water + carbon dioxide	$\text{CuCO}_3 + 2 \text{HCl} \rightarrow \text{CuCl}_2 + \text{H}_2\text{O} + \text{CO}_2$
hydrogencarbonate + acid → salt + water + carbon dioxide	$\text{KHCO}_3 + \text{HCl} \rightarrow \text{KCl} + \text{H}_2\text{O} + \text{CO}_2$
ammonia + acid → ammonium salt	$\text{NH}_3 + \text{HCl} \rightarrow \text{NH}_4\text{Cl}$
metal carbonate → metal oxide + carbon dioxide (on heating)	$\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$

### **TASK 4 – WRITING BALANCED EQUATIONS**

1) Balance the following equations.

- $\text{Mg} + \text{HNO}_3 \rightarrow \text{Mg}(\text{NO}_3)_2 + \text{H}_2$
- $\text{CuCl}_2 + \text{NaOH} \rightarrow \text{Cu}(\text{OH})_2 + \text{NaCl}$
- $\text{SO}_2 + \text{O}_2 \rightarrow \text{SO}_3$
- $\text{C}_4\text{H}_{10} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$

2) Give balanced equations for the following reactions.

- sodium + oxygen → sodium oxide
- aluminium + chlorine → aluminium chloride
- calcium + hydrochloric acid → calcium chloride + hydrogen
- ammonia + sulfuric acid → ammonium sulfate

## TASK 5 – WRITING BALANCED EQUATIONS 2

Write balance equations for the following reactions:

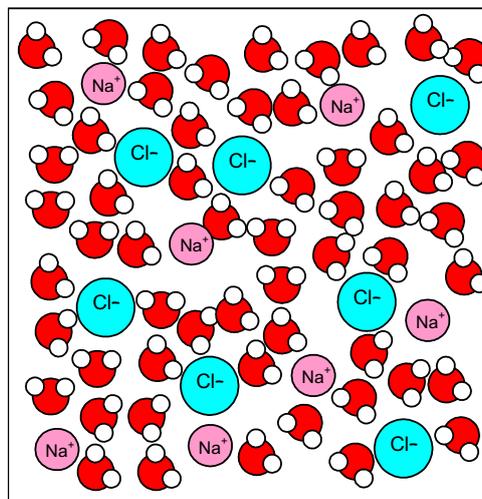
- 1) burning aluminium
- 2) burning hexane (C<sub>6</sub>H<sub>14</sub>)
- 3) burning ethanethiol (CH<sub>3</sub>CH<sub>2</sub>SH)
- 4) reaction of lithium with water
- 5) reaction of calcium carbonate with nitric acid
- 6) thermal decomposition of lithium carbonate
- 7) reaction of ammonia with nitric 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:

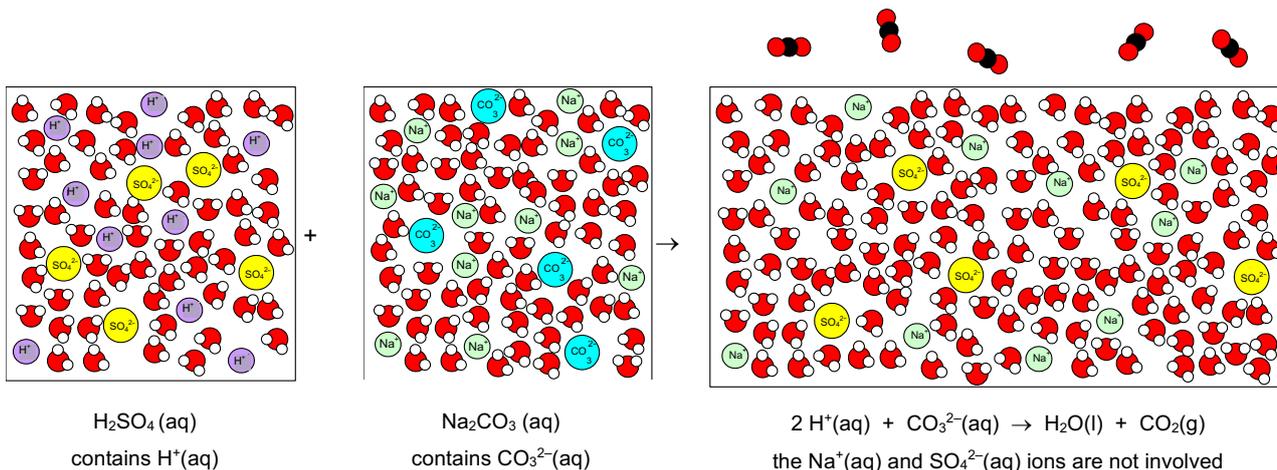
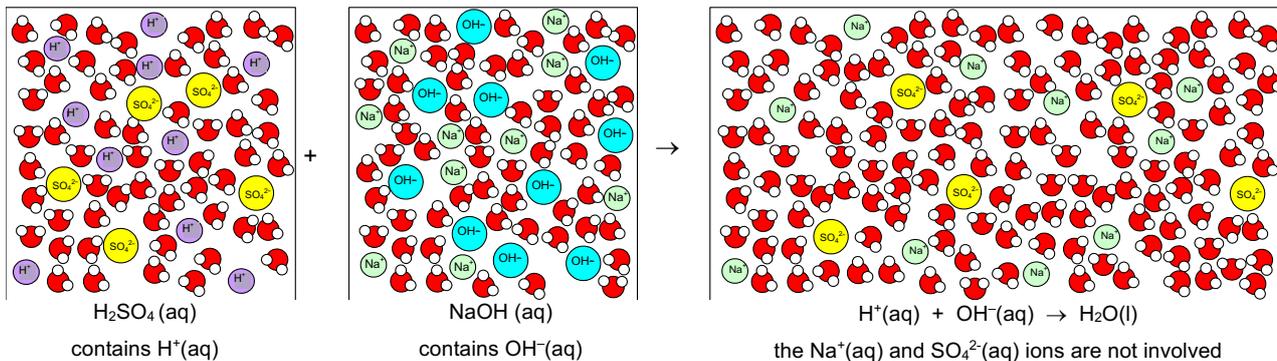


#### **Reactions of acids:**

Common ionic equations are:	acid + hydroxide	$\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l})$
	acid + carbonate	$2 \text{H}^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$
	acid + hydrogencarbonate	$\text{H}^+(\text{aq}) + \text{HCO}_3^-(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$
	acid + ammonia	$\text{H}^+(\text{aq}) + \text{NH}_3(\text{aq}) \rightarrow \text{NH}_4^+(\text{aq})$

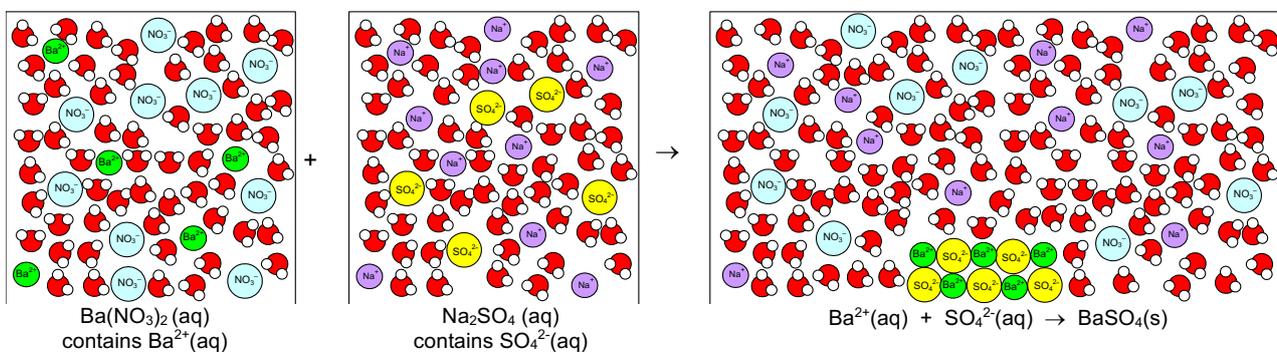
We can even use these ionic equations to work out the ratio in which acids react without writing any equation.

For example, in the reaction of H<sub>2</sub>SO<sub>4</sub>(aq) with NaOH(aq) we know that one lot of H<sub>2</sub>SO<sub>4</sub> contains two lots of H<sup>+</sup> ions. As H<sup>+</sup> ions react with OH<sup>-</sup> ions in the ratio 1:1 [H<sup>+</sup>(aq) + OH<sup>-</sup>(aq) → H<sub>2</sub>O(l)] we know that we need two lots of NaOH to provide two lots of OH<sup>-</sup> ions to react with the two lots of H<sup>+</sup> ions. Therefore, one lot of H<sub>2</sub>SO<sub>4</sub> reacts with two lots of NaOH, i.e. the reacting ratio of H<sub>2</sub>SO<sub>4</sub> : NaOH = 1:2

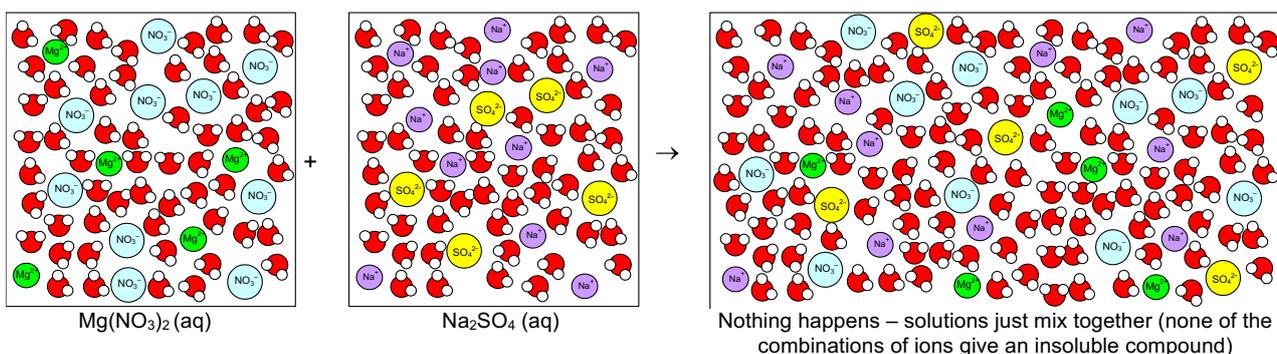


### Precipitation reactions

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.



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.



## **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.
- reaction of hydrochloric acid (aq) with potassium hydroxide (aq)
  - precipitation of silver(I) iodide from reaction between silver(I) nitrate (aq) and potassium iodide (aq)
  - reaction of potassium carbonate (aq) with nitric acid (aq)
  - precipitation of calcium hydroxide from reaction between sodium hydroxide (aq) and calcium chloride (aq)
  - reaction of ammonia (aq) with hydrochloric acid (aq)
  - reaction of sodium hydrogencarbonate (aq) with sulfuric acid (aq)
  - precipitation of calcium sulfate from reaction between calcium chloride (aq) and sulfuric acid (aq)
  - precipitation of lead(II) chloride from reaction between lead(II) nitrate (aq) and sodium chloride (aq)
  - 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  $A \times 10^n$  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	$3.435 \times 10^3$	$1.029 \times 10^6$	$2.5 \times 10^{-2}$	$2.32 \times 10^1$	$2.78 \times 10^{-5}$

- 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.

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

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

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

### 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.

$$\text{Energy released} = 263 + 1282 = 1545 \text{ kJ (answer is to nearest unit as both values are to nearest unit)}$$

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

$$\text{Mass} = 0.154 + 0.01234 = 0.166 \text{ g (answer is to nearest 0.001 g as least precise number is to nearest 0.001 g)}$$

## **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) $6125 \times 384$    | ..... | d) $7550 / 25$             | ..... |
| b) $25.00 \times 0.010$ | ..... | e) $0.000152 \times 13.00$ | ..... |
| c) $13.5 + 0.18$        | ..... | f) $0.0125 \times 0.025$   | ..... |
- 3) Write the following numbers in non standard form.
- |                         |       |                          |       |
|-------------------------|-------|--------------------------|-------|
| a) $1.5 \times 10^{-3}$ | ..... | d) $5.34 \times 10^2$    | ..... |
| b) $4.6 \times 10^{-4}$ | ..... | e) $1.03 \times 10^6$    | ..... |
| c) $3.575 \times 10^5$  | ..... | f) $8.35 \times 10^{-3}$ | ..... |
- 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) $6.125 \times 10^{-3} \times 3.5$                 | ..... |
| b) $4.3 \times 10^{-4} / 7.00$                       | ..... |
| 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 – RELATIVE MASS

- Most elements are made of up atoms of different isotopes (e.g. chlorine contains both  $^{35}\text{Cl}$  and  $^{37}\text{Cl}$  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.

<b>Relative atomic mass, <math>A_r</math></b>	Average mass of an atom of an element relative to $\frac{1}{12}$ th the mass of $^{12}\text{C}$ atom
<b>Relative formula mass, <math>M_r</math></b>	<i>If referring specifically to a molecule (relative molecular mass)</i>
	Average mass of a molecule of a substance relative to $\frac{1}{12}$ th the mass of $^{12}\text{C}$ atom
	<i>More generally for any substance</i>
	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  $\text{F}_2$  .....
- 2  $\text{Fe}$  .....
- 3  $\text{H}_2\text{SO}_4$  .....
- 4  $\text{Al}_2\text{O}_3$  .....
- 5  $\text{Mg}(\text{OH})_2$  .....
- 6  $\text{Al}(\text{NO}_3)_3$  .....
- 7  $(\text{NH}_4)_2\text{SO}_4$  .....
- 8  $\text{CuCO}_3$  .....
- 9  $\text{AgNO}_3$  .....
- 10  $\text{NH}_4\text{NO}_3$  .....
- 11  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$  .....
- 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  $6.022 \times 10^{23}$  of those things. One mole of bananas is  $6.022 \times 10^{23}$  bananas. One mole of water molecules is  $6.022 \times 10^{23}$  water molecules
- This number is known as the Avogadro constant ( $= 6.022 \times 10^{23} \text{ mol}^{-1}$ ).
- 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 is 18.0 grams.



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



1 ton = 1,000,000 g ( $10^6$ )

1 kg = 1,000 g ( $10^3$ )

1 mg = 0.001 g ( $10^{-3}$ )

Remember *Mr Moles!*

### TASK 9A – MOLES

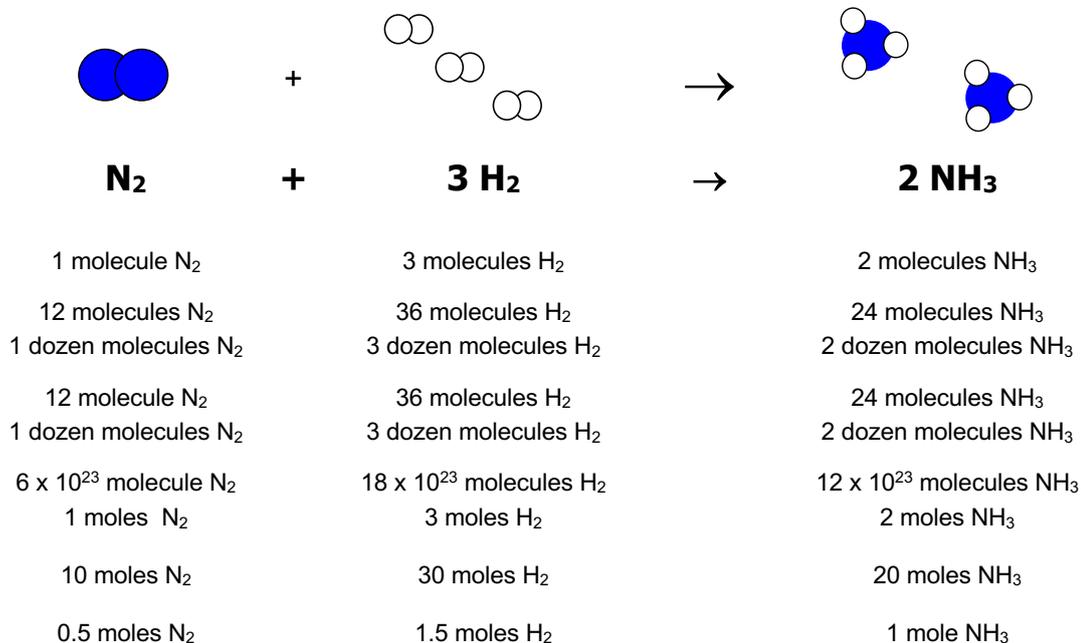
- 1) How many moles are there in each of the following?
  - a) 72.0 g of Mg
  - b) 4.00 kg of CuO
  - c) 39.0 g of  $\text{Al}(\text{OH})_3$
  - d) 1.00 tonne of NaCl
  - e) 20.0 mg of  $\text{Cu}(\text{NO}_3)_2$
- 2) What is the mass of each of the following?
  - a) 5.00 moles of  $\text{Cl}_2$
  - b) 0.200 moles of  $\text{Al}_2\text{O}_3$
  - c) 0.0100 moles of Ag
  - d) 0.00200 moles of  $(\text{NH}_4)_2\text{SO}_4$
  - e) 0.300 moles of  $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$
- 3)
  - a) Calculate the number of moles of  $\text{CO}_2$  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  $\text{Al}_2\text{O}_3$  in 5.10 g of  $\text{Al}_2\text{O}_3$
  - b) Calculate the number of moles of  $\text{Al}^{3+}$  ions in 5.10 g of  $\text{Al}_2\text{O}_3$
  - a) Calculate the number of moles of  $\text{O}^{2-}$  ions in 5.10 g of  $\text{Al}_2\text{O}_3$
- 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.

### TASK 9B – AVOGADRO CONSTANT

- 1) Calculate the mass of one atom of  $^{12}\text{C}$
- 2) Calculate the number of  $\text{H}_2\text{O}$  molecules in 9.0 g of water.
- 3) Calculate the number of atoms in 42.0 g of nitrogen gas.

## 6 – REACTING MASS CALCULATIONS

### What a chemical equation means

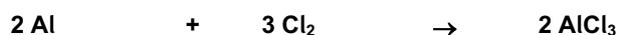


### TASK 10 – WHAT EQUATIONS MEAN



12 mol

0.1 mol



5 mol

0.1 mol



0.5 mol

20 mol



0.5 mol

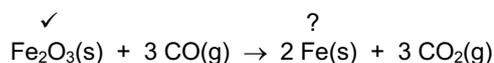
10 mol

## 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?



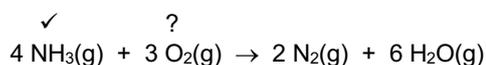
$$\text{moles of Fe}_2\text{O}_3 = \frac{\text{mass (g)}}{M_r} = \frac{32000}{159.6} = 200.5 \text{ mol}$$

1 mole of Fe<sub>2</sub>O<sub>3</sub> forms 2 moles of Fe

$$\therefore \text{moles of Fe} = 2 \times 200.5 = 401.0 \text{ mol}$$

$$\therefore \text{mass of Fe} = \text{moles} \times M_r = 401.0 \times 55.8 = \mathbf{22,400 \text{ g (3 sig fig)}}$$

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



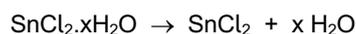
$$\text{moles of NH}_3 = \frac{\text{mass (g)}}{M_r} = \frac{102}{17.0} = 6.00 \text{ mol}$$

4 moles of NH<sub>3</sub> reacts with 3 moles of O<sub>2</sub> ∴ 1 mole of NH<sub>3</sub> reacts with  $\frac{3}{4}$  mole of O<sub>2</sub>

$$\therefore \text{moles of O}_2 = 6.00 \times \frac{3}{4} = 4.50 \text{ mol}$$

$$\therefore \text{mass of O}_2 = \text{moles} \times M_r = 4.50 \times 32.0 = \mathbf{144 \text{ g (3 sig fig)}}$$

- e.g.** When 5.00 g of crystals of hydrated tin (II) chloride, SnCl<sub>2</sub>.xH<sub>2</sub>O, are heated, 4.20 g of anhydrous tin(II) chloride are formed. Calculate the number of molecules of water of crystallisation are in SnCl<sub>2</sub>.xH<sub>2</sub>O (i.e. the value of x).



$$\text{moles of SnCl}_2 = \frac{\text{mass (g)}}{M_r} = \frac{4.20}{189.7} = 0.02214 \text{ moles}$$

$$\therefore \text{moles of SnCl}_2 \cdot x\text{H}_2\text{O} = 0.02214 \text{ mol}$$

$$\therefore M_r \text{ of SnCl}_2 \cdot x\text{H}_2\text{O} = \frac{\text{mass (g)}}{\text{moles}} = \frac{5.00}{0.02214} = 225.8$$

$$\therefore M_r \text{ of } x\text{H}_2\text{O} = 225.8 - 189.7 = 36.1$$

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

## **TASK 11 – REACTING MASS CALCULATIONS 1**

- 1) What mass of hydrogen is needed to react with 40.0 g of copper(II) oxide?  
 $\text{CuO} + \text{H}_2 \rightarrow \text{Cu} + \text{H}_2\text{O}$
- 2) What mass of oxygen reacts with 192 g of magnesium?  
 $2 \text{Mg} + \text{O}_2 \rightarrow 2 \text{MgO}$
- 3) What mass of sulfur trioxide is formed from 96.0 g of sulfur dioxide?  
 $2 \text{SO}_2 + \text{O}_2 \rightarrow 2 \text{SO}_3$
- 4) What mass of carbon monoxide is needed to react with 480 kg of iron(III) oxide?  
 $\text{Fe}_2\text{O}_3 + 3 \text{CO} \rightarrow 2 \text{Fe} + 3 \text{CO}_2$
- 5) What mass of carbon dioxide is produced when 5.60 g of butene is burnt.  
 $\text{C}_4\text{H}_8 + 6 \text{O}_2 \rightarrow 4 \text{CO}_2 + 4 \text{H}_2\text{O}$
- 6) What mass of oxygen is needed to react with 8.50 g of hydrogen sulfide ( $\text{H}_2\text{S}$ )?  
 $2 \text{H}_2\text{S} + 3 \text{O}_2 \rightarrow 2 \text{SO}_2 + 2 \text{H}_2\text{O}$
- 7) 4.92 g of hydrated magnesium sulfate crystals ( $\text{MgSO}_4 \cdot n\text{H}_2\text{O}$ ) 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  $n$ .  
 $\text{MgSO}_4 \cdot n\text{H}_2\text{O} \rightarrow \text{MgSO}_4 + n \text{H}_2\text{O}$
- 8) In an experiment to find the value of  $x$  in the compound  $\text{MgBr}_2 \cdot x\text{H}_2\text{O}$ , 7.30 g of the compound on heating to constant mass gave 4.60 g of the anhydrous salt  $\text{MgBr}_2$ . Find the value of  $x$ .  
 $\text{MgBr}_2 \cdot x\text{H}_2\text{O} \rightarrow \text{MgBr}_2 + x \text{H}_2\text{O}$
- 9) What mass of glucose must be fermented to give 5.00 kg of ethanol?  
 $\text{C}_6\text{H}_{12}\text{O}_6 \rightarrow 2 \text{C}_2\text{H}_5\text{OH} + 2 \text{CO}_2$
- 10) The pollutant sulfur dioxide can be 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?  
 $2 \text{CaCO}_3 + 2 \text{SO}_2 + \text{O}_2 \rightarrow 2 \text{CaSO}_4 + 2 \text{CO}_2$
- 11) What mass of potassium oxide is formed when 7.80 mg of potassium is burned in oxygen?  
 $4 \text{K} + \text{O}_2 \rightarrow 2 \text{K}_2\text{O}$
- 12) What mass of hydrogen is produced when 10.0 g of aluminium reacts with excess hydrochloric acid?  
 $2 \text{Al} + 6 \text{HCl} \rightarrow 2 \text{AlCl}_3 + 3 \text{H}_2$
- 13) What mass of sodium just reacts with 40.0 g of oxygen?  
 $4 \text{Na} + \text{O}_2 \rightarrow 2 \text{Na}_2\text{O}$
- 14) What mass of nitrogen is produced when 2.00 tonnes of ammonia gas decomposes?  
 $2 \text{NH}_3 \rightarrow \text{N}_2 + 3 \text{H}_2$
- 15) What mass of oxygen is produced when 136 g of hydrogen peroxide molecules decompose?  
 $2 \text{H}_2\text{O}_2 \rightarrow 2 \text{H}_2\text{O} + \text{O}_2$
- 16) What mass of lead(II) oxide is produced when 0.400 moles of lead(II) nitrate decomposes?  
 $2 \text{Pb}(\text{NO}_3)_2 \rightarrow 2 \text{PbO} + 4 \text{NO}_2 + \text{O}_2$

## 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:  $\text{C}_3\text{H}_8 + 5 \text{O}_2 \rightarrow 3 \text{CO}_2 + 4 \text{H}_2\text{O}$

How many moles of products are formed when 1 mole of  $\text{C}_3\text{H}_8$  is mixed with 8 moles of  $\text{O}_2$ ?

	$\text{C}_3\text{H}_8$	+	$5 \text{O}_2$	$\rightarrow$	$3 \text{CO}_2$	+	$4 \text{H}_2\text{O}$
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	$1 - 1 = 0 \text{ mol}$		$8 - 5 = 3 \text{ mol}$		$0 + 3 = 3 \text{ mol}$		$0 + 4 = 4 \text{ mol}$
	$\text{C}_3\text{H}_8$ limiting reagent		$\text{O}_2$ in excess				

e.g. Sulfur dioxide reacts with oxygen as shown:  $2 \text{SO}_2 + \text{O}_2 \rightarrow 2 \text{SO}_3$

How many moles of  $\text{SO}_3$  are formed when 5 mole of  $\text{SO}_2$  is mixed with 2 moles of  $\text{O}_2$ ?

	$2 \text{SO}_2$	+	$\text{O}_2$	$\rightarrow$	$2 \text{SO}_3$
moles at the start	5 mol		2 mol		
change in moles	4 mol react		2 mol react		4 mol made
moles at the end	$5 - 4 = 1 \text{ mol}$		$2 - 2 = 0 \text{ mol}$		$0 + 4 = 4 \text{ mol}$
	$\text{SO}_2$ in excess		$\text{O}_2$ 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?



	$\text{TiCl}_4$	+	$2 \text{Mg}$	$\rightarrow$	<b>Ti</b>	+	$2 \text{MgCl}_2$
moles at the start	$\frac{1000}{189.9} = 5.266 \text{ mol}$		$\frac{100}{24.3} = 4.115 \text{ mol}$				
	5.266 moles of $\text{TiCl}_4$ needs 10.53 moles of Mg to react						
	∴ $\text{TiCl}_4$ is in excess and does not all react, so Mg is the limiting reagent						
	∴ 2.058 moles of $\text{TiCl}_4$ 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					$0 + 2.058 = 2.058 \text{ mol}$		

∴ Mass of Ti =  $2.058 \times M_r = 2.058 \times 47.9 = 98.6 \text{ g}$

**TASK 12A – LIMITING REAGENTS 1**

<b><u>1</u></b>	<b>CaO</b>	<b>+</b>	<b>H<sub>2</sub>O</b>	<b>→</b>	<b>Ca(OH)<sub>2</sub></b>	
a)	2 mol		3 mol			
b)	10 mol		8 mol			
c)	0.40 mol		0.50 mol			
<b><u>2</u></b>	<b>2Ca</b>	<b>+</b>	<b>O<sub>2</sub></b>	<b>→</b>	<b>2CaO</b>	
a)	2 mol		2 mol			
b)	10 mol		2 mol			
c)	0.50 mol		0.20 mol			
<b><u>3</u></b>	<b>2Fe</b>	<b>+</b>	<b>3Cl<sub>2</sub></b>	<b>→</b>	<b>2FeCl<sub>3</sub></b>	
a)	3 mol		3 mol			
b)	12 mol		15 mol			
c)	20 mol		40 mol			
<b><u>4</u></b>	<b>TiCl<sub>4</sub></b>	<b>+</b>	<b>4Na</b>	<b>→</b>	<b>Ti</b>	<b>+</b> <b>4NaCl</b>
a)	4 mol		4 mol			
b)	2 mol		10 mol			
c)	0.5 mol		1 mol			
<b><u>5</u></b>	<b>C<sub>2</sub>H<sub>5</sub>OH</b>	<b>+</b>	<b>3O<sub>2</sub></b>	<b>→</b>	<b>2CO<sub>2</sub></b>	<b>+</b> <b>3H<sub>2</sub>O</b>
a)	15 mol		30 mol			
b)	0.25 mol		1 mol			
c)	3 mol		6 mol			
<b><u>6</u></b>	<b>N<sub>2</sub></b>	<b>+</b>	<b>3H<sub>2</sub></b>	<b>→</b>	<b>2NH<sub>3</sub></b>	
a)	3 mol		6 mol			
b)	0.5 mol		0.9 mol			
c)	6 mol		20 mol			
<b><u>7</u></b>	<b>4K</b>	<b>+</b>	<b>O<sub>2</sub></b>	<b>→</b>	<b>2K<sub>2</sub>O</b>	
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? | $\text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2$                       |
| 2 | What mass of magnesium bromide is formed when 1.00 g of magnesium reacts with 5.00 g of bromine?   | $\text{Mg} + \text{Br}_2 \rightarrow \text{MgBr}_2$                                 |
| 3 | What mass of copper is formed when 2.00 g of copper(II) oxide reacts with 1.00 g of hydrogen?      | $\text{CuO} + \text{H}_2 \rightarrow \text{Cu} + \text{H}_2\text{O}$                |
| 4 | What mass of sodium fluoride is formed when 2.30 g of sodium reacts with 2.85 g of fluorine?       | $2\text{Na} + \text{F}_2 \rightarrow 2\text{NaF}$                                   |
| 5 | What mass of iron is formed when 8.00 g of iron(III) oxide reacts with 2.16 g of aluminium?        | $\text{Fe}_2\text{O}_3 + 2\text{Al} \rightarrow 2\text{Fe} + \text{Al}_2\text{O}_3$ |
| 6 | What mass of aluminium chloride is formed when 13.5 g of aluminium reacts with 42.6 g of chlorine? | $2\text{Al} + 3\text{Cl}_2 \rightarrow 2\text{AlCl}_3$                              |

## **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?
- $$\text{Fe} + \text{S} \rightarrow \text{FeS}$$
- 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?
- $$\text{H}_2\text{SO}_4 + 2 \text{NH}_3 \rightarrow (\text{NH}_4)_2\text{SO}_4$$
- 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?
- $$2 \text{NH}_4\text{Cl} + \text{CaO} \rightarrow \text{CaCl}_2 + \text{H}_2\text{O} + 2 \text{NH}_3$$
- 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?
- $$\text{TiCl}_4 + 2 \text{Mg} \rightarrow \text{Ti} + 2 \text{MgCl}_2$$
- 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?
- $$\text{N}_2 + 3 \text{H}_2 \rightarrow 2 \text{NH}_3$$
- 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?
- $$2 \text{SO}_2 + \text{O}_2 \rightarrow 2 \text{SO}_3$$
- 7) Hydrazine ( $\text{N}_2\text{H}_4$ ) 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)?
- $$2 \text{NH}_3 + \text{NaOCl} \rightarrow \text{N}_2\text{H}_4 + \text{NaCl} + \text{H}_2\text{O}$$



- 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  $MgSO_4 \cdot 7H_2O$  and  $CuSO_4 \cdot 5H_2O$  is heated at  $120^\circ C$  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  $MgSO_4 \cdot 7H_2O$  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.

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

**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.

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

$$\therefore \text{ moles of W} = 2157 \text{ mol}$$

$$\therefore \text{ mass of W} = \text{moles} \times M_r = 2157 \times 183.8 = \mathbf{396000 \text{ g}} \text{ (3 sig fig)}$$

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

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

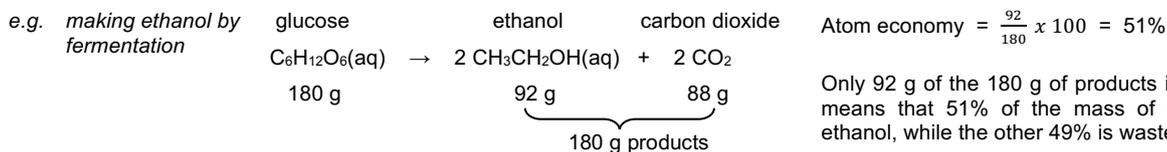
## **TASK 13 – PERCENTAGE YIELD**

- 1) Sulfur dioxide reacts with oxygen to make sulfur trioxide.  $2 \text{SO}_2 + \text{O}_2 \rightarrow 2 \text{SO}_3$
- 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.
  - In the reaction, only 90.0 g of sulfur trioxide was made. Calculate the percentage yield.
  - 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.  $\text{Fe}_2\text{O}_3 + 3 \text{CO} \rightarrow 2 \text{Fe} + 3 \text{CO}_2$
- Calculate the maximum theoretical mass of iron that can be made from 1.00 tonne of iron(III) oxide.
  - 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.  $\text{N}_2 + 3 \text{H}_2 \rightarrow 2 \text{NH}_3$
- Calculate the maximum theoretical mass of ammonia that can be made by reacting 90.0 g of hydrogen with an excess of nitrogen.
  - 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.  $\text{TiCl}_4 + 2 \text{Mg} \rightarrow \text{Ti} + 2 \text{MgCl}_2$
- Calculate the maximum theoretical mass of titanium that can be extracted from 100 g of titanium chloride .
  - In the reaction, only 20.0 g of titanium was made. Calculate the percentage yield.
  - 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.  $2 \text{Al}_2\text{O}_3 \rightarrow 4 \text{Al} + 3 \text{O}_2$
- Calculate the maximum theoretical mass of aluminium that can be made from 1.00 kg of aluminium oxide.
  - In the reaction, only 500 g of aluminium was made. Calculate the percentage yield.
- 6) The fertiliser ammonium sulfate is made as follows.  $2 \text{NH}_3 + \text{H}_2\text{SO}_4 \rightarrow (\text{NH}_4)_2\text{SO}_4$
- 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.
  - In the reaction, only 300 g of ammonium sulfate was produced. Calculate the percentage yield.
- 7) 0.8500 g of hexanone,  $\text{C}_6\text{H}_{12}\text{O}$ , is converted into its 2,4-dinitrophenylhydrazone during its analysis. After isolation and purification, 2.1180 g of product  $\text{C}_{12}\text{H}_{18}\text{N}_4\text{O}_4$  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.

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



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

- Calculate the percentage atom economy to make sodium from sodium chloride.  $2 \text{NaCl} \rightarrow 2 \text{Na} + \text{Cl}_2$
- Calculate the percentage atom economy to make hydrogen from the reaction of zinc with hydrochloric acid.  $\text{Zn} + 2 \text{HCl} \rightarrow \text{ZnCl}_2 + \text{H}_2$
- Calculate the percentage atom economy to make iron from iron(III) oxide in the Blast Furnace.  $\text{Fe}_2\text{O}_3 + 3 \text{CO} \rightarrow 2 \text{Fe} + 3 \text{CO}_2$
- Calculate the percentage atom economy to make calcium oxide from calcium carbonate.  $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$
- Calculate the percentage atom economy to make sulfur trioxide from sulfur dioxide.  $2 \text{SO}_2 + \text{O}_2 \rightarrow 2 \text{SO}_3$
- Calculate the percentage atom economy to make oxygen from hydrogen peroxide.  $2 \text{H}_2\text{O}_2 \rightarrow 2 \text{H}_2\text{O} + \text{O}_2$
- Hydrazine ( $\text{N}_2\text{H}_4$ ) was used as the rocket fuel for the Apollo missions to the moon. It is by reaction of ammonia ( $\text{NH}_3$ ) with sodium chlorate(I) ( $\text{NaOCl}$ ).  
$$\text{ammonia} + \text{sodium chlorate} \rightarrow \text{hydrazine} + \text{sodium chloride} + \text{water}$$
$$2 \text{NH}_3 + \text{NaOCl} \rightarrow \text{N}_2\text{H}_4 + \text{NaCl} + \text{H}_2\text{O}$$
  - Calculate the maximum theoretical mass of hydrazine that can be made by reacting 340 g of ammonia with an excess of sodium chlorate.
  - In the reaction, only 280 g of hydrazine was produced. Calculate the percentage yield.
  - Calculate the percentage atom economy for this way of making hydrazine.
  - 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<sub>2</sub> (giant covalent) – the ratio of Si:O atoms in the lattice is 1:2  
Al<sub>2</sub>O<sub>3</sub> (ionic) – the ratio of Al<sup>3+</sup>:O<sup>2-</sup> ions in the lattice is 2:3  
H<sub>2</sub>O (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<sub>2</sub>, M<sub>r</sub> = 42.0

$$\text{Formula mass of empirical formula} = 14.0 \quad \therefore \frac{M_r}{M_r \text{ of empirical formula}} = \frac{42.0}{14.0} = 3$$

Molecular formula = 3 x empirical formula = C<sub>3</sub>H<sub>6</sub>

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

- Write out the mass or percentage of each element,
- Divide each mass or percentage by the A<sub>r</sub> of the element (**not the M<sub>r</sub>**)
- 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%.

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

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

∴ empirical formula = Fe<sub>3</sub>O<sub>4</sub>

e.g. ii) 0.25 g of hydrogen reacts with oxygen to produce 4.25 g of hydrogen peroxide (M<sub>r</sub> = 34.0).

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

$$\text{H } \frac{0.25}{1.0} = 0.25 \quad \text{O } \frac{4.00}{16.0} = 0.25$$

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

1 : 1

∴ 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<sub>2</sub>O<sub>2</sub>

## **TASK 15 – EMPIRICAL & 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.

$$PV = nRT$$

P = pressure (Pa)

n = number of moles

V = volume (m<sup>3</sup>)

R = gas constant (8.31 J mol<sup>-1</sup> K<sup>-1</sup>)

T = temperature (K)

Volume		Pressure		Temperature
dm <sup>3</sup> × 10 <sup>-3</sup> = m <sup>3</sup>	cm <sup>3</sup> × 10 <sup>-6</sup> = m <sup>3</sup>	kPa × 10 <sup>3</sup> = Pa	MPa × 10 <sup>6</sup> = 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<sup>3</sup>

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

## TASK 16 – THE IDEAL GAS EQUATION

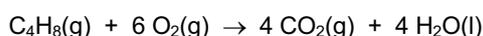
- Convert the following into SI units.  
a) 200°C    b) 98 kPa    c) 50 cm<sup>3</sup>    d) -50°C    e) 0.1 MPa    f) 3.2 dm<sup>3</sup>
- Calculate the volume that 0.400 moles of an ideal gas occupies at 100°C (3sf) and a pressure of 1000 kPa (4sf).
- How many moles of gas occupy 19400 cm<sup>3</sup> at 27.0°C and 101 kPa pressure?
- Calculate the pressure that 0.0500 moles of gas, which occupies a volume of 200 cm<sup>3</sup> (3sf) exerts at a temperature of 50.0 K.
- 0.140 moles of a gas has a volume of 2.00 dm<sup>3</sup> at a pressure of 90.0 kPa. Calculate the temperature of the gas.
- At 273 K and 101000 Pa, 6.319 g of a gas occupies 2.00 dm<sup>3</sup>. Calculate the relative molecular mass of the gas.
- Find the volume of ethyne (C<sub>2</sub>H<sub>2</sub>) that can be prepared from 10.0 g of calcium carbide at 20.0°C and 100 kPa (3sf).  
CaC2(s) + 2 H2O(l) -> Ca(OH)2(aq) + C2H2(g)
- Find the volume of gas formed when 1.00 g of strontium nitrate decomposes at 100 kPa (3sf) and 525°C  
2 Sr(NO3)2(s) -> 2 SrO(s) + 4 NO2(g) + O2(g)
- What mass of potassium chlorate(V) must be heated to give 1.00 dm<sup>3</sup> of oxygen at 20.0°C and 0.100 MPa.  
2 KClO3(s) -> 2 KCl(s) + 3 O2(g)
- 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 H2O(l) -> 2 NaOH(aq) + H2(g)
- 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?  
C3H8(g) + 5 O2(g) -> 3 CO2(g) + 4 H2O(g)

- 12) Calculate the relative molecular mass of a gas which has a density of  $2.615 \text{ g dm}^{-3}$  at  $298 \text{ K}$  and  $101 \text{ kPa}$ .
- 13) A certain mass of an ideal gas is in a sealed vessel of volume  $3.25 \text{ dm}^3$ . At a temperature of  $25.0^\circ\text{C}$  it exerts a pressure of  $101 \text{ kPa}$ . What pressure will it exert at  $100^\circ\text{C}$ ?
- 14) An ideal gas occupies a volume of  $2.75 \text{ dm}^3$  at  $290\text{K}$  (3sf) and  $8.70 \times 10^4 \text{ Pa}$ . At what temperature will it occupy  $3.95 \text{ dm}^3$  at  $1.01 \times 10^5 \text{ Pa}$ ?

## **REACTING GAS VOLUMES**

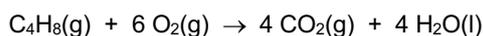
- The volume of a gas depends on the temperature, pressure and number of moles. What the gas is does not affect its volume.
- This means that under the same conditions of temperature and pressure,  $100 \text{ cm}^3$  (as an example) of one gas contains the same number of moles as  $100 \text{ cm}^3$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

e.g. What volume of oxygen reacts with  $100 \text{ cm}^3$  of but-1-ene?



Answer =  $600 \text{ cm}^3$

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



$6 \text{ dm}^3$  of  $\text{O}_2$  reacts with  $1 \text{ dm}^3$  of but-1-ene  $\therefore 4 \text{ dm}^3$  of oxygen is left over

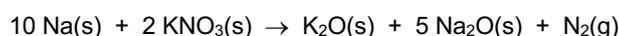
## **TASK 17 – REACTING GAS VOLUMES**

- 1) What volume of oxygen is required to burn the following gases, and what volume of carbon dioxide is produced?
- a)  $1 \text{ dm}^3$  of methane  $\text{CH}_4(\text{g}) + 2 \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{l})$
- b)  $20 \text{ cm}^3$  of butene  $\text{C}_4\text{H}_8(\text{g}) + 6 \text{O}_2(\text{g}) \rightarrow 4 \text{CO}_2(\text{g}) + 4 \text{H}_2\text{O}(\text{l})$
- c)  $500 \text{ cm}^3$  of ethyne  $2 \text{C}_2\text{H}_2(\text{g}) + 5 \text{O}_2(\text{g}) \rightarrow 4 \text{CO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{l})$
- d)  $750 \text{ cm}^3$  of benzene  $2 \text{C}_6\text{H}_6(\text{g}) + 15 \text{O}_2(\text{g}) \rightarrow 12 \text{CO}_2(\text{g}) + 6 \text{H}_2\text{O}(\text{l})$
- 2) When  $100 \text{ cm}^3$  of hydrogen bromide reacts with  $80 \text{ cm}^3$  of ammonia, a white solid is formed and some gas is left over. What gas and how much of it is left over?
- $$\text{NH}_3(\text{g}) + \text{HBr}(\text{g}) \rightarrow \text{NH}_4\text{Br}(\text{s})$$
- 3)  $100 \text{ cm}^3$  of methane was reacted with  $500 \text{ cm}^3$  of oxygen. What is the total volume of all gases at the end, and indicate how much there is of each gas?
- $$\text{CH}_4(\text{g}) + 2 \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{l})$$
- 4) If  $4 \text{ dm}^3$  of hydrogen sulfide is burned in  $10 \text{ dm}^3$  of oxygen, what is the final volume of the mixture (give the volume of each gas at the end)?
- $$2 \text{H}_2\text{S}(\text{g}) + 3 \text{O}_2(\text{g}) \rightarrow 2 \text{H}_2\text{O}(\text{g}) + 2 \text{SO}_2(\text{g})$$
- 5)  $0.50 \text{ dm}^3$  of a gaseous alkane  $\text{C}_n\text{H}_{2n+2}$  undergoes complete combustion with  $6.25 \text{ dm}^3$  of oxygen. Give the formula of the alkane.



# 2

- 1) A gas has a density of  $1.655 \text{ g dm}^{-3}$  at  $323 \text{ K}$  and  $1.01 \times 10^5 \text{ Pa}$ . 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.



- 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  $60.0 \text{ dm}^3$  air bag at room temperature and atmospheric pressure.
- 3)  $1.00 \text{ g}$  of sulfur dissolved completely in an excess of liquid ammonia to give  $420 \text{ cm}^3$  of hydrogen sulfide ( $\text{H}_2\text{S}$ ), measured at  $273 \text{ K}$  and  $101 \text{ kPa}$ , and also a solid containing the elements nitrogen and sulfur. Deduce the empirical formula of the solid.
  - 4) When  $15 \text{ cm}^3$  of a gaseous hydrocarbon was exploded with  $60 \text{ cm}^3$  of oxygen (an excess), the final volume was  $45 \text{ cm}^3$ . This decreased to  $15 \text{ cm}^3$  on treatment with  $\text{NaOH}$  solution (which removes  $\text{CO}_2$ ). 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  $298 \text{ K}$  and  $100 \text{ kPa}$ .
  - 6)  $10 \text{ cm}^3$  of a hydrocarbon,  $\text{C}_x\text{H}_y$ , were exploded with an excess of oxygen. There was a contraction in volume of  $30 \text{ cm}^3$ . When the products were treated with sodium hydroxide (which reacts with carbon dioxide), there was a further contraction of  $30 \text{ cm}^3$ . 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    | ..... | e) phosphorus        | ..... |
| b) lead                | ..... | f) nitrogen          | ..... |
| c) chromium(III) oxide | ..... | g) barium hydroxide  | ..... |
| d) ammonium sulfate    | ..... | 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)

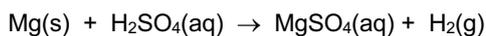
Acid	Formula of acid	Base	Formula of base	Molar ratio of acid:base
sulfuric acid		potassium hydroxide		
hydrochloric acid		potassium hydrogencarbonate		
nitric acid		ammonia		
hydrochloric acid		zinc carbonate		

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  $^{12}\text{C}$  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).
- $\text{N}_2 + 3 \text{H}_2 \rightarrow 2 \text{NH}_3$
- a) 5.00 moles of  $\text{N}_2$  + 5.00 moles of  $\text{H}_2$       moles of  $\text{NH}_3$  formed = ..... (1)
- b) 2.00 moles of  $\text{N}_2$  + 5.00 moles of  $\text{H}_2$       moles of  $\text{NH}_3$  formed = ..... (1)
- c) 10.0 moles of  $\text{N}_2$  + 50.0 moles of  $\text{H}_2$       moles of  $\text{NH}_3$  formed = ..... (1)
- d) 0.200 moles of  $\text{N}_2$  + 0.0500 moles of  $\text{H}_2$       moles of  $\text{NH}_3$  formed = ..... (1)
- 6) Calculate the volume of 0.200 moles of carbon dioxide at  $100^\circ\text{C}$  and 2.00 MPa pressure.  
 .....  
 .....  
 .....  
 ..... (3)
- 7) Calculate the number of moles of argon in  $200 \text{ cm}^3$  (3sf) at 100 kPa (3sf) at  $20.0^\circ\text{C}$ .  
 .....  
 .....  
 .....  
 ..... (3)
- 8) The equation is for the combustion of ethane in oxygen.  $\text{C}_2\text{H}_6(\text{g}) + 3\frac{1}{2} \text{O}_2(\text{g}) \rightarrow 2 \text{CO}_2(\text{g}) + 3 \text{H}_2\text{O}(\text{l})$
- 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  $\text{cm}^3$  of ethane + 100  $\text{cm}^3$  of oxygen  
 volume of  $\text{CO}_2$  formed = .....      Total volume of gases at end = ..... (2)
- b) 100  $\text{cm}^3$  of ethane + 500  $\text{cm}^3$  of oxygen  
 volume of  $\text{CO}_2$  formed = .....      Total volume of gases at end = ..... (2)
- c) 200  $\text{cm}^3$  of ethane + 400  $\text{cm}^3$  of oxygen  
 volume of  $\text{CO}_2$  formed = .....      Total volume of gases at end = ..... (2)

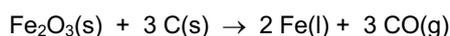
- 9) What volume of hydrogen is formed at 20.0°C and 100000 Pa (3sf) pressure when 2.00 g of magnesium is reacted with excess sulfuric acid?



.....  
.....  
.....  
.....

(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?



.....  
.....  
.....  
.....

(4)

- 11) a) In 20 moles of  $\text{Al}_2\text{O}_3$ ,

- i) how many moles of  $\text{Al}^{3+}$  ions? .....
- ii) how many moles of  $\text{O}^{2-}$  ions? .....

(2)

- b) In 360 g of water

- i) how many moles of H atoms? .....
- ii) how many moles of O atoms? .....

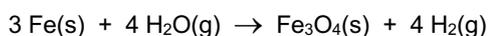
(2)

- 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  $\text{Fe}_3\text{O}_4$  is produced when 140 g of iron reacts with excess steam?



.....  
.....  
.....

(3)

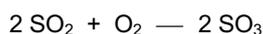
- 13) What mass of potassium oxide is formed when 7.80 g of potassium is burned in oxygen?



.....  
.....  
.....

(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.



.....  
.....  
.....

(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.



.....  
.....  
.....

(3)

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

.....

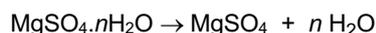
(1)

c) Calculate the percentage atom economy for this process.

.....

(1)

- 16) When 12.30 g of  $\text{MgSO}_4 \cdot n\text{H}_2\text{O}$  is heated gently until no further change in mass occurs, to remove the water of crystallisation, 6.00 g of anhydrous magnesium sulfate ( $\text{MgSO}_4$ ) remained. Work out the relative formula mass ( $M_r$ ) of the  $\text{MgSO}_4 \cdot n\text{H}_2\text{O}$ , and so the value of  $n$ .

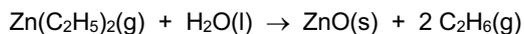


.....  
.....  
.....  
.....  
.....

(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:



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  $\text{H}^+(\text{aq})$ . The equation for the reaction between zinc(II) oxide and acid is:
- $$\text{ZnO}(\text{s}) + 2 \text{H}^+(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + \text{H}_2\text{O}(\text{l})$$
- 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

- Use the volume and concentration of one reactant to calculate the moles.
- Use the balanced (or ionic) equation to find the moles of the other reactant.
- Calculate the volume or concentration as required of that reactant.

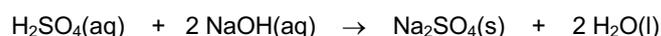
$$\text{concentration} = \frac{\text{moles}}{\text{volume (dm}^3\text{)}}$$

### Note

- Volume in  $\text{dm}^3 = \frac{\text{volume in cm}^3}{1000}$  (e.g.  $25 \text{ cm}^3 \rightarrow \frac{25}{1000} = 0.025 \text{ dm}^3$ )
- Concentration in  $\text{g dm}^{-3} = \text{concentration in mol dm}^{-3} \times M_r$  (e.g.  $\text{H}_2\text{SO}_4 \text{ } 0.10 \text{ mol dm}^{-3} \rightarrow 0.10 \times 98 \text{ dm}^{-3} = 9.8 \text{ g dm}^{-3}$ )
- In many titrations, a standard solution of one the reagents is made (typically  $250 \text{ cm}^3$  in a volumetric flask) and  $25 \text{ cm}^3$  portions of this standard solution are used in each titration.

type of acid	what it means	examples	reacting ratio with NaOH
monoprotic	one $\text{H}^+$ ion per unit	HCl, $\text{HNO}_3$ , $\text{CH}_3\text{COOH}$	1 : 1 (acid : NaOH)
diprotic	two $\text{H}^+$ ions per unit	$\text{H}_2\text{SO}_4$	1 : 2 (acid : NaOH)
triprotic	three $\text{H}^+$ ions per unit	$\text{H}_3\text{PO}_4$	1 : 3 (acid : NaOH)

**E.g. 1:**  $25.0 \text{ cm}^3$  of  $0.020 \text{ mol dm}^{-3}$  sulfuric acid neutralises  $18.6 \text{ cm}^3$  of sodium hydroxide solution.



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

$$\text{moles of H}_2\text{SO}_4 = \text{conc} \times \text{vol (dm}^3\text{)} = 0.020 \times \frac{25.0}{1000} = 0.000500$$

$$\text{moles of NaOH} = \text{conc} \times \text{vol (dm}^3\text{)} = 2 \times \text{moles H}_2\text{SO}_4 = 0.000500 \times 2 = 0.00100$$

$$\text{concentration of NaOH} = \frac{\text{moles}}{\text{volume (dm}^3\text{)}} = \frac{0.00100}{\frac{18.6}{1000}} = \mathbf{0.0538 \text{ mol dm}^{-3}}$$

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

$$M_r \text{ of NaOH} = 23.0 + 16.0 + 1.0 = 40.0$$

$$\text{mass of NaOH in } 1 \text{ dm}^3 = M_r \times \text{moles} = 40.0 \times 0.0538 = 2.15 \text{ g}$$

$$\text{concentration} = \mathbf{2.15 \text{ g dm}^{-3}}$$

**E.g. 2:** Crystals of citric acid contain water of crystallisation ( $\text{C}_6\text{H}_8\text{O}_7 \cdot n\text{H}_2\text{O}$ ). Citric acid is a triprotic acid.  $1.52 \text{ g}$  of the citric acid was made up to  $250 \text{ cm}^3$  solution.  $25 \text{ cm}^3$  portions of this solution required  $21.80 \text{ cm}^3$  of  $0.100 \text{ mol dm}^{-3}$  sodium hydroxide for neutralisation. Calculate the  $M_r$  and the value of  $n$ .

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

$$\text{Moles of C}_6\text{H}_8\text{O}_7 \cdot n\text{H}_2\text{O} \text{ in each titration} = \frac{0.00218}{3} = 0.000727 \quad (1 \text{ mol of acid reacts with 3 mol of NaOH})$$

$$\text{Moles of C}_6\text{H}_8\text{O}_7 \cdot n\text{H}_2\text{O} \text{ in } 250 \text{ cm}^3 \text{ solution} = 0.000727 \times 10 = 0.00727$$

$$M_r \text{ of C}_6\text{H}_8\text{O}_7 \cdot n\text{H}_2\text{O} = \frac{\text{mass}}{\text{moles}} = \frac{1.52}{0.00727} = \mathbf{209.2}$$

$$M_r \text{ of nH}_2\text{O} = 209.2 - 192.0 = 17.2 \quad n = \frac{17.2}{18.0} = 0.954 = \mathbf{1} \quad (\mathbf{n \text{ is a whole number}})$$

## **TASK 18 – SOLUTION CALCULATIONS**

- 1) Calculate the number of moles in the following.
- 2 dm<sup>3</sup> of 0.05 mol dm<sup>-3</sup> HCl
  - 50 litres of 5 mol dm<sup>-3</sup> H<sub>2</sub>SO<sub>4</sub>
  - 10 cm<sup>3</sup> of 0.25 mol dm<sup>-3</sup> KOH
- 2) Calculate the concentration of the following in **both** mol dm<sup>-3</sup> and g dm<sup>-3</sup>
- 0.400 moles of HCl in 2.00 litres of solution
  - 12.5 moles of H<sub>2</sub>SO<sub>4</sub> in 5.00 dm<sup>3</sup> of solution
  - 1.05 g of NaOH in 500 cm<sup>3</sup> of solution
- 3) Calculate the volume of each solution that contains the following number of moles.
- 0.00500 moles of NaOH from 0.100 mol dm<sup>-3</sup> solution
  - 1.00 x 10<sup>-5</sup> moles of HCl from 0.0100 mol dm<sup>-3</sup> solution
- 4) 25.0 cm<sup>3</sup> of 0.020 mol dm<sup>-3</sup> sulfuric acid neutralises 18.6 cm<sup>3</sup> of barium hydroxide solution.
- $$\text{H}_2\text{SO}_4 + \text{Ba}(\text{OH})_2 \rightarrow \text{BaSO}_4 + 2 \text{H}_2\text{O}$$
- Find the concentration of the barium hydroxide solution in mol dm<sup>-3</sup>
  - Find the concentration of the barium hydroxide solution in g dm<sup>-3</sup>
- 5) 25.0 cm<sup>3</sup> of a solution of sodium hydroxide required 18.8 cm<sup>3</sup> of 0.0500 mol dm<sup>-3</sup> H<sub>2</sub>SO<sub>4</sub>
- $$\text{H}_2\text{SO}_4 + 2 \text{NaOH} \rightarrow \text{Na}_2\text{SO}_4 + 2 \text{H}_2\text{O}$$
- Find the concentration of the sodium hydroxide solution in mol dm<sup>-3</sup>
  - Find the concentration of the sodium hydroxide solution in g dm<sup>-3</sup>
- 6) Calculate the volume of 0.05 mol dm<sup>-3</sup> KOH is required to neutralise 25.0 cm<sup>3</sup> of 0.0150 mol dm<sup>-3</sup> HNO<sub>3</sub>.
- $$\text{HNO}_3 + \text{KOH} \rightarrow \text{KNO}_3 + \text{H}_2\text{O}$$
- 7) 25.0 cm<sup>3</sup> of arsenic acid, H<sub>3</sub>AsO<sub>4</sub>, required 37.5 cm<sup>3</sup> of 0.100 mol dm<sup>-3</sup> sodium hydroxide for neutralisation.
- $$3 \text{NaOH}(\text{aq}) + \text{H}_3\text{AsO}_4(\text{aq}) \rightarrow \text{Na}_3\text{AsO}_4(\text{aq}) + 3 \text{H}_2\text{O}(\text{l})$$
- Find the concentration of the acid in mol dm<sup>-3</sup>
  - Find the concentration of the acid in g dm<sup>-3</sup>
- 8) A 250 cm<sup>3</sup> solution of NaOH was prepared. 25.0 cm<sup>3</sup> of this solution required 28.2 cm<sup>3</sup> of 0.100 mol dm<sup>-3</sup> HCl for neutralisation. Calculate what mass of NaOH was dissolved to make up the original 250 cm<sup>3</sup> solution.
- $$\text{HCl} + \text{NaOH} \rightarrow \text{NaCl} + \text{H}_2\text{O}$$
- 9) What volume of 5.00 mol dm<sup>-3</sup> HCl is required to neutralise 20.0 kg of CaCO<sub>3</sub>?
- $$2 \text{HCl} + \text{CaCO}_3 \rightarrow \text{CaCl}_2 + \text{H}_2\text{O} + \text{CO}_2$$
- 10) 3.88 g of a monoprotic acid was dissolved in water and the solution made up to 250 cm<sup>3</sup>. 25.0 cm<sup>3</sup> of this solution was titrated with 0.095 mol dm<sup>-3</sup> NaOH solution, requiring 46.5 cm<sup>3</sup>. Calculate the relative molecular mass of the acid.

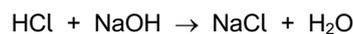
- 11) A 1.575 g sample of ethanedioic acid crystals,  $\text{H}_2\text{C}_2\text{O}_4 \cdot n\text{H}_2\text{O}$ , was dissolved in water and made up to  $250 \text{ cm}^3$ . One mole of the acid reacts with two moles of NaOH. In a titration,  $25.0 \text{ cm}^3$  of this solution of acid reacted with exactly  $15.6 \text{ cm}^3$  of  $0.160 \text{ mol dm}^{-3}$  NaOH. Calculate the value of  $n$ .
- 12) A solution of a metal carbonate,  $\text{M}_2\text{CO}_3$ , was prepared by dissolving 7.46 g of the anhydrous solid in water to give  $1000 \text{ cm}^3$  of solution.  $25.0 \text{ cm}^3$  of this solution reacted with  $27.0 \text{ cm}^3$  of  $0.100 \text{ mol dm}^{-3}$  hydrochloric acid. Calculate the relative formula mass of  $\text{M}_2\text{CO}_3$  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  $\text{CaCO}_3$  we have (let's call it  $p$  moles). We add 10 moles of HCl (an excess). The excess is made into a  $250 \text{ cm}^3$  solution in a volumetric flask and then  $25 \text{ cm}^3$  portions of it require 0.4 moles of NaOH for neutralisation.



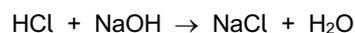
- This means that there is  $10 \times 0.4$  moles (= 4 moles) of left over HCl in the volumetric flask solution (as we used  $1/10^{\text{th}}$  of the solution in the volumetric flask in each titration)
- This means that 6 moles ( $10 - 4$  moles) of HCl reacted with the  $\text{CaCO}_3$
- This means that there must have been 3 moles of  $\text{CaCO}_3$  (i.e.  $p = 3$ ) in the first place (remember that 2 moles of HCl reacts with each mole of  $\text{CaCO}_3$ ).

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  $250 \text{ cm}^3$  stock solution. We titrate  $25 \text{ cm}^3$  portions of the solution which require 0.01 moles of HCl for neutralisation. Calculate the original moles of aspirin.

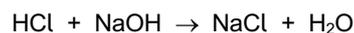
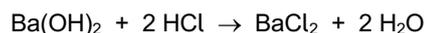
e.g. Malachite is an ore containing copper carbonate,  $\text{CuCO}_3$ . We add 5.00 moles of HCl (an excess) to some crushed malachite and make the resulting solution into a  $250 \text{ cm}^3$  stock solution. We titrate  $25 \text{ cm}^3$  portions of the solution which require 0.15 moles of NaOH for neutralisation. Calculate the original moles of copper carbonate in the malachite.

## TASK 19 – BACK TITRATION CALCULATIONS

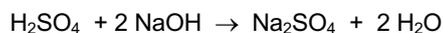
- 1) Limestone is mainly calcium carbonate. A student wanted to find what percentage of some limestone was calcium carbonate. A 1.00 g sample of limestone is allowed to react with 100 cm<sup>3</sup> of 0.200 mol dm<sup>-3</sup> HCl. The excess acid required 24.8 cm<sup>3</sup> of 0.100 mol dm<sup>-3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



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



- 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<sup>3</sup> solution. 25.0 cm<sup>3</sup> of this solution required 0.0300 moles of sodium hydroxide for neutralisation.



- 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<sup>3</sup> of 1.00 mol dm<sup>-3</sup>). She then titrated the excess against 0.500 mol dm<sup>-3</sup> NaOH requiring 25.8 cm<sup>3</sup> of the NaOH. Calculate the mass of calcium carbonate in the tablet.

- 5) A sample containing ammonium chloride was warmed with 100 cm<sup>3</sup> of 1.00 mol dm<sup>-3</sup> sodium hydroxide solution. After the ammonia had reacted the excess sodium hydroxide required 50.0 cm<sup>3</sup> of 0.250 mol dm<sup>-3</sup> 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<sup>3</sup> 0.200 mol dm<sup>-3</sup> sodium hydroxide solution giving off ammonia gas. The remaining NaOH that was not used required 28.7 cm<sup>3</sup> of 0.100 mol dm<sup>-3</sup> 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<sub>2</sub>OCl<sub>6</sub> and that of **B** is Si<sub>3</sub>O<sub>2</sub>Cl<sub>8</sub>.

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<sup>3</sup> of 0.0500 mol dm<sup>-3</sup> 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.

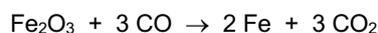


# Calculation

## 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.

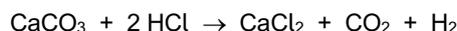
- 3) What mass of carbon monoxide is needed to react with 1.00 kg of iron(III) oxide?



- 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?

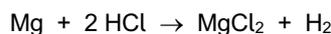


- 5) What volume of 0.100 mol dm<sup>-3</sup> hydrochloric acid would react with 25.0 g of calcium carbonate?



- 6) 25.0 cm<sup>3</sup> of 0.0400 mol dm<sup>-3</sup> sodium hydroxide solution reacted with 20.75 cm<sup>3</sup> 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<sup>3</sup>. 25.00 cm<sup>3</sup> portions of this were titrated against 0.2500 mol dm<sup>-3</sup> sodium hydroxide, requiring 23.50 cm<sup>3</sup>. 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<sup>3</sup> of 1.00 mol dm<sup>-3</sup> hydrochloric acid. The copper does not react, but the magnesium does as shown:



The resulting solution was filtered to remove unreacted copper and then made up to 250 cm<sup>3</sup> with water. 25.0 cm<sup>3</sup> of this solution was found to neutralise 36.8 cm<sup>3</sup> of 0.200 mol dm<sup>-3</sup> 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<sup>3</sup> of 2.00 mol dm<sup>-3</sup> hydrochloric acid (only the calcium carbonate reacts). The resulting solution was made up to 250 cm<sup>3</sup> with water and a 25.0 cm<sup>3</sup> portion of this needed 34.1 cm<sup>3</sup> of 0.200 mol dm<sup>-3</sup> 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<sub>4</sub>ClO<sub>4</sub>).
- 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 <sub>2</sub> CO <sub>3</sub>	3	K <sub>2</sub> O	4	Fe <sub>2</sub> O <sub>3</sub>	5	CrCl <sub>3</sub>	6	Ca(OH) <sub>2</sub>
7	Al(NO <sub>3</sub> ) <sub>3</sub>	8	Na <sub>2</sub> SO <sub>4</sub>	9	PbO	10	Na <sub>3</sub> PO <sub>4</sub>	11	Zn(HCO <sub>3</sub> ) <sub>2</sub>	12	(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>
13	Ga(OH) <sub>3</sub>	14	SrSe	15	RaSO <sub>4</sub>	16	Na <sub>3</sub> N				

### **TASK 2 – Writing formulas 1**

1	PbO <sub>2</sub>	2	Cu	3	Na	4	NH <sub>4</sub> Cl	5	NH <sub>3</sub>	6	S <sub>8</sub>
7	H <sub>2</sub> SO <sub>4</sub>	8	Ne	9	SiO <sub>2</sub>	10	Si	11	Ba(OH) <sub>2</sub>	12	SnCl <sub>4</sub>
13	AgNO <sub>3</sub>	14	I <sub>2</sub>	15	Ni	16	H <sub>2</sub> S	17	TiO <sub>2</sub>	18	Pb
19	SrSO <sub>4</sub>	20	Li								

### **TASK 3 – Writing formulas 2**

1	Ag <sub>2</sub> CO <sub>3</sub>	2	Au	3	PtF <sub>2</sub>	4	HNO <sub>3</sub>	5	NH <sub>3</sub>	6	SiH <sub>4</sub>
7	P <sub>4</sub>	8	C	9	V <sub>2</sub> O <sub>5</sub>	10	Co(OH) <sub>2</sub>	11	Ba(OH) <sub>2</sub>	12	NH <sub>3</sub>
13	HCl	14	F <sub>2</sub>	15	Si	16	Ca <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>	17	Rb	18	GeO <sub>2</sub>
19	MgAt <sub>2</sub>	20	NO								

### **TASK 4 – Writing balanced equations 1**

- $\text{Mg} + 2 \text{HNO}_3 \rightarrow \text{Mg}(\text{NO}_3)_2 + \text{H}_2$
  - $\text{CuCl}_2 + 2 \text{NaOH} \rightarrow \text{Cu}(\text{OH})_2 + 2 \text{NaCl}$
  - $2 \text{SO}_2 + \text{O}_2 \rightarrow 2 \text{SO}_3$
  - $\text{C}_4\text{H}_{10} + 6\frac{1}{2} \text{O}_2 \rightarrow 4 \text{CO}_2 + 5 \text{H}_2\text{O}$  or  $2 \text{C}_4\text{H}_{10} + 13 \text{O}_2 \rightarrow 8 \text{CO}_2 + 10 \text{H}_2\text{O}$
- $4 \text{Na} + \text{O}_2 \rightarrow 2 \text{Na}_2\text{O}$
  - $2 \text{Al} + 3 \text{Cl}_2 \rightarrow 2 \text{AlCl}_3$
  - $\text{Ca} + 2 \text{HCl} \rightarrow \text{CaCl}_2 + \text{H}_2$
  - $2 \text{NH}_3 + \text{H}_2\text{SO}_4 \rightarrow (\text{NH}_4)_2\text{SO}_4$

### **TASK 5 – Writing balanced equations 2**

- $4 \text{Al} + 3 \text{O}_2 \rightarrow 2 \text{Al}_2\text{O}_3$
- $\text{C}_6\text{H}_{14} + 9\frac{1}{2} \text{O}_2 \rightarrow 6 \text{CO}_2 + 7 \text{H}_2\text{O}$  or  $2 \text{C}_6\text{H}_{14} + 19 \text{O}_2 \rightarrow 12 \text{CO}_2 + 14 \text{H}_2\text{O}$
- $\text{CH}_3\text{CH}_2\text{SH} + 4\frac{1}{2} \text{O}_2 \rightarrow 2 \text{CO}_2 + \text{SO}_2 + 3 \text{H}_2\text{O}$  or  $2 \text{CH}_3\text{CH}_2\text{SH} + 9 \text{O}_2 \rightarrow 4 \text{CO}_2 + 2 \text{SO}_2 + 6 \text{H}_2\text{O}$
- $2 \text{Li} + 2 \text{H}_2\text{O} \rightarrow 2 \text{LiOH} + \text{H}_2$
- $\text{CaCO}_3 + 2 \text{HNO}_3 \rightarrow \text{Ca}(\text{NO}_3)_2 + \text{H}_2\text{O} + \text{CO}_2$
- $\text{Li}_2\text{CO}_3 \rightarrow \text{Li}_2\text{O} + \text{CO}_2$

- 7  $\text{NH}_3 + \text{HNO}_3 \rightarrow \text{NH}_4\text{NO}_3$
- 8  $\text{K}_2\text{O} + \text{H}_2\text{SO}_4 \rightarrow \text{K}_2\text{SO}_4 + \text{H}_2\text{O}$
- 9  $\text{Ca}(\text{OH})_2 + 2 \text{HCl} \rightarrow \text{CaCl}_2 + 2 \text{H}_2\text{O}$
- 10  $3 \text{Zn} + 2 \text{H}_3\text{PO}_4 \rightarrow \text{Zn}_3(\text{PO}_4)_2 + 3 \text{H}_2$
- 11  $2 \text{NaHCO}_3 + \text{H}_2\text{SO}_4 \rightarrow \text{Na}_2\text{SO}_4 + 2 \text{H}_2\text{O} + 2 \text{CO}_2$
- 12  $2 \text{KOH} + \text{H}_2\text{SO}_4 \rightarrow \text{K}_2\text{SO}_4 + 2 \text{H}_2\text{O}$

### **TASK 6 – Ionic equations**

- 1  $\text{HCl}$ ,  $\text{LiOH}$ , 1:1;  $\text{H}_2\text{SO}_4$ ,  $\text{NaHCO}_3$ , 1:2;  $\text{HNO}_3$ ,  $\text{NH}_3$ , 1:1;  $\text{H}_2\text{SO}_4$ ,  $\text{K}_2\text{CO}_3$ , 1:1,  $\text{HNO}_3$ ,  $\text{Sr}(\text{OH})_2$ , 2:1
- 2
  - a  $\text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O}$
  - b  $\text{Ag}^+ + \text{I}^- \rightarrow \text{AgI}$
  - c  $2 \text{H}^+ + \text{CO}_3^{2-} \rightarrow \text{H}_2\text{O} + \text{CO}_2$
  - d  $\text{Ca}^{2+} + 2 \text{OH}^- \rightarrow \text{Ca}(\text{OH})_2$
  - e  $\text{NH}_3 + \text{H}^+ \rightarrow \text{NH}_4^+$
  - f  $\text{H}^+ + \text{HCO}_3^- \rightarrow \text{H}_2\text{O} + \text{CO}_2$
  - g  $\text{Ca}^{2+} + \text{SO}_4^{2-} \rightarrow \text{CaSO}_4$
  - h  $\text{Pb}^{2+} + 2 \text{Cl}^- \rightarrow \text{PbCl}_2$
  - i  $\text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O}$

### **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 $1.64 \times 10^{-4}$ | b $5.24 \times 10^{-2}$      | c $1.5 \times 10^{-8}$ | d $3.45 \times 10^4$ | e $6.2 \times 10^{-1}$ | f $8.7 \times 10^7$           |
| 5 | a 0.021 (2sf)           | b $6.1 \times 10^{-5}$ (2sf) | c $4.0 \times 10^8$    | d 2400               | e 0.0610               | f $8.00 \times 10^{-7}$ (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 9A – 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      |          |          |           |            |

### **TASK 9B – Avogadro number**

- 1  $1.99 \times 10^{-23}$  g
- 2  $3.011 \times 10^{23}$
- 3  $1.81 \times 10^{24}$

### **TASK 10 – What equations mean**

- 1  $12 \text{ mol Na} + 3 \text{ mol O}_2 \rightarrow 6 \text{ mol Na}_2\text{O}$ ;  $0.1 \text{ mol Na} + 0.025 \text{ mol O}_2 \rightarrow 0.05 \text{ mol Na}_2\text{O}$
- 2  $5 \text{ mol Al} + 7.5 \text{ mol Cl}_2 \rightarrow 5 \text{ mol AlCl}_3$ ;  $0.1 \text{ mol Al} + 0.15 \text{ mol Cl}_2 \rightarrow 0.1 \text{ mol AlCl}_3$
- 3  $0.5 \text{ mol C}_4\text{H}_{10} + 3.25 \text{ mol O}_2 \rightarrow 2 \text{ mol CO}_2 + 2.5 \text{ mol H}_2\text{O}$ ;  $20 \text{ mol C}_4\text{H}_{10} + 130 \text{ mol O}_2 \rightarrow 80 \text{ mol CO}_2 + 100 \text{ mol H}_2\text{O}$
- 4  $0.5 \text{ mol NH}_3 + 0.375 \text{ mol O}_2 \rightarrow 0.25 \text{ mol N}_2 + 0.75 \text{ mol H}_2\text{O}$ ;  $10 \text{ mol NH}_3 + 7.5 \text{ mol O}_2 \rightarrow 5 \text{ mol N}_2 + 15 \text{ mol H}_2\text{O}$

### **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	$\text{NaHCO}_3 = 3.51 \text{ g}$ , $\text{Na}_2\text{CO}_3 = 6.49 \text{ g}$	2	$\text{CaCO}_3 = 40.3\%$ , $\text{MgCO}_3 = 59.7\%$	3	$\text{C}_4\text{H}_8$	4	26.6%
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### **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 $\text{CH}_3$	b $\text{P}_2\text{O}_3$	c $\text{SO}_2$	d $\text{CH}_2$					
	e $\text{CH}_2\text{O}$	f $\text{C}_2\text{H}_7\text{N}$	g $\text{B}_3\text{H}_5$	h $\text{C}_{12}\text{H}_{22}\text{O}_{11}$					
2	a $\text{N}_2\text{H}_4$	b $\text{C}_4\text{H}_{10}$	c $\text{C}_5\text{H}_{10}$	d $\text{PH}_3$	e $\text{C}_6\text{H}_6$	f $\text{C}_3\text{H}_6$			
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 $\text{CaBr}_2$	b $\text{Na}_2\text{S}_2\text{O}_3$	c $\text{C}_2\text{H}_7\text{N}$	d $\text{CO}_2$	e $\text{NO}_2$				
5	$\text{FeCl}_3$	6 $\text{K}_2\text{SO}_4$	7 $\text{P}_2\text{O}_3$ , $\text{P}_4\text{O}_6$	8 $\text{CH}_2\text{O}$ , $\text{C}_2\text{H}_4\text{O}_2$					
9	$\text{C}_5\text{H}_{10}\text{O}$ , $\text{C}_5\text{H}_{10}\text{O}$		10 $x = 4$ , $y = 2$						

### **TASK 16 – Ideal gas equation**

- 1 a 473 K b 98000 Pa c  $50 \times 10^{-6} \text{ m}^3$  d 223 K e 100000 Pa f  $3.2 \times 10^{-3} \text{ m}^3$   
2  $1.24 \times 10^{-3} \text{ m}^3$  3 0.786 4 104000 Pa 5 155 K 6 71.0 7  $0.00380 \text{ m}^3$   
8  $7.75 \times 10^{-4} \text{ m}^3$  9 3.36 g 10 0.000538  $\text{m}^3$  11 4.53  $\text{m}^3$  12 64.1 13 483 K  
14 126000 Pa

### **TASK 17 – Reacting gas volumes**

- 1 a  $\text{O}_2$  2  $\text{dm}^3$ ,  $\text{CO}_2$  1  $\text{dm}^3$  b  $\text{O}_2$  120  $\text{cm}^3$ ,  $\text{CO}_2$  80  $\text{cm}^3$   
c  $\text{O}_2$  1250  $\text{cm}^3$ ,  $\text{CO}_2$  1000  $\text{cm}^3$  d  $\text{O}_2$  5625  $\text{cm}^3$ ,  $\text{CO}_2$  4500  $\text{cm}^3$   
2 20  $\text{cm}^3$  HBr left at end  
3 300  $\text{cm}^3$   $\text{O}_2$ , 100  $\text{cm}^3$   $\text{CO}_2$ , total 400  $\text{cm}^3$  gas at end  
4 4  $\text{dm}^3$   $\text{O}_2$ , 4  $\text{dm}^3$   $\text{H}_2\text{O}$ , 4  $\text{dm}^3$   $\text{SO}_2$ , total 12  $\text{dm}^3$  gas  
5  $\text{C}_8\text{H}_{18}$

### **CHALLENGE 2**

- 1 44.0 2 3.21 : 1, 130.5 g 3 NS 4  $\text{C}_2\text{H}_4$  5 515  $\text{ms}^{-1}$  6  $\text{C}_3\text{H}_8$

### **Calculations CHECK-UP**

- 1 a  $\text{Zn}(\text{NO}_3)_2$  b Pb c  $\text{Cr}_2\text{O}_3$  d  $(\text{NH}_4)_2\text{SO}_4$   
e  $\text{P}_4$  f  $\text{N}_2$  g  $\text{Ba}(\text{OH})_2$  h  $\text{Al}_2(\text{SO}_4)_3$   
2  $\text{H}_2\text{SO}_4$ , KOH, 1:2; HCl,  $\text{KHCO}_3$ , 1:1;  $\text{HNO}_3$ ,  $\text{NH}_3$ , 1:1; HCl,  $\text{ZnCO}_3$ , 2:1  
3 a  $\text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O}$  b  $\text{Ba}^{2+} + \text{SO}_4^{2-} \rightarrow \text{BaSO}_4$   
c  $\text{H}^+ + \text{NH}_3 \rightarrow \text{NH}_4^+$  d  $\text{H}^+ + \text{HCO}_3^- \rightarrow \text{H}_2\text{O} + \text{CO}_2$   
4 a average mass of an atom, relative to  $1/12^{\text{th}}$  mass of  $^{12}\text{C}$  atom b it is the agreed standard  
c mixture of other isotopes  
5 a  $\text{H}_2$ ,  $\text{NH}_3 = 3.33$  b  $\text{H}_2$ ,  $\text{NH}_3 = 3.33$   
c  $\text{N}_2$ ,  $\text{NH}_3 = 20.0$  d  $\text{H}_2$ ,  $\text{NH}_3 = 0.033$   
6  $3.10 \times 10^{-4} \text{ m}^3$  7  $8.21 \times 10^{-3}$   
8 a volume of  $\text{CO}_2 = 57.1 \text{ cm}^3$ , total = 128.5  $\text{cm}^3$  b volume of  $\text{CO}_2 = 200 \text{ cm}^3$ , total = 350  $\text{cm}^3$   
c volume of  $\text{CO}_2 = 229 \text{ cm}^3$ , total = 314  $\text{cm}^3$   
9  $2.00 \times 10^{-3} \text{ m}^3$  10 1.64  $\text{m}^3$   
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,  $1.22 \times 10^{-3} \text{ m}^3$ , 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  $\text{mol dm}^{-3}$ , 7.3  $\text{g dm}^{-3}$  b 2.5  $\text{mol dm}^{-3}$ , 245.3  $\text{g dm}^{-3}$  c 0.0525  $\text{mol dm}^{-3}$ , 2.10  $\text{g dm}^{-3}$   
3 a 0.05  $\text{dm}^3$  b 0.001  $\text{dm}^3$   
4 0.0269  $\text{mol dm}^{-3}$ , 4.61  $\text{g dm}^{-3}$  5 0.0752  $\text{mol dm}^{-3}$ , 3.01  $\text{g dm}^{-3}$  6 0.0075  $\text{dm}^3$   
7 0.0500  $\text{mol dm}^{-3}$ , 7.10  $\text{g dm}^{-3}$  8 1.13 g 9 79.9  $\text{dm}^3$   
10 87.8 11 2 12  $A_r = 39.1$ , K

### **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

### **CHALLENGE 3**

1 9.67%            2 A  $\text{Si}_2\text{OCl}_6$

### **Calculation Allsorts**

1  $\text{C}_5\text{H}_{11}\text{NO}$       2  $\text{C}_{11}\text{H}_{14}\text{O}_2$ ,  $\text{C}_{11}\text{H}_{14}\text{O}_2$             3 526 g            4 2.71 g            5 5.00 dm<sup>3</sup>  
6 0.0241 mol dm<sup>-3</sup>            7 234.9            8 3.21%            9 55.0%  
10  $10 \text{ Al} + 6 \text{ NH}_4\text{ClO}_4 \rightarrow 3 \text{ N}_2 + 9 \text{ H}_2\text{O} + 6 \text{ HCl} + 5 \text{ Al}_2\text{O}_3$