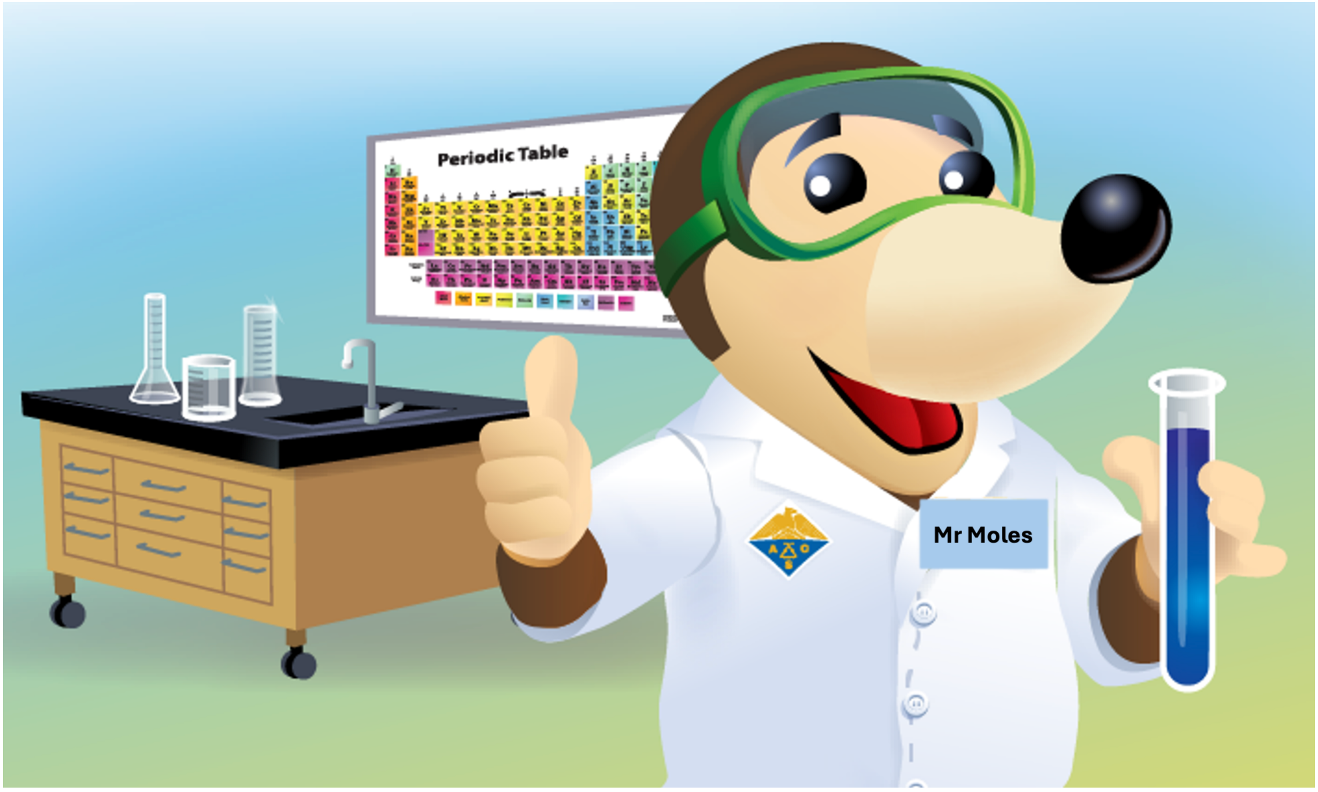
AMOUNT OF SUBSTANCE



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1 – FORMULAS & STRUCTURE TYPES

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

You have to know and be able to use the information on this page – you should not be looking it up. No one will tell you the charge on an ion at A level!

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

Structure types

	Monatomic	Simple molecular	Ionic	Metallic	Giant covalent
Elements	Group 0 elements (e.g. He)	Most non-metal elements (e.g. O_2)		Metallic elements (e.g. Cu)	Carbon (graphite, diamond, graphene), Silicon
Compounds		Most compounds made from non-metal combined (e.g. $C_6H_{12}O_6$)	Most compounds made from metals combined with non-metals (e.g. Na_2O)		Silicon dioxide (SiO_2)

Formulas of elements

Monatomic	Simple molecular	Ionic	Metallic	Giant covalent
He helium Ne neon Ar argon Kr krypton Xe xenon Rn radon	H_2 hydrogen N_2 nitrogen O_2 oxygen F_2 fluorine Cl_2 chlorine Br_2 bromine I_2 iodine P_4 phosphorus (white) S_8 sulfur C_{60} carbon (buckminsterfullerene)	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 carbon (diamond) C carbon (graphite) C carbon (graphene) Si silicon

Formulas of Compounds

Monatomic	Simple molecular	Ionic	Metallic	Giant covalent
There are no monatomic compounds!!	Some common molecular compounds: CO_2 carbon dioxide CO carbon monoxide NO nitrogen monoxide NO_2 nitrogen dioxide SO_2 sulfur dioxide SO_3 sulfur trioxide NH_3 ammonia CH_4 methane H_2S hydrogen sulfide	These have to be worked out using ion charges – you have to know these. LEARN them ASAP. Note these acids: HCl hydrochloric acid H_2SO_4 sulfuric acid HNO_3 nitric acid H_3PO_4 phosphoric acid	There are no metallic compounds!!	SiO_2 silicon dioxide (silica)

ION CHARGES

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

Writing ionic formulas

Key principle	The number of positive charges must equal the number of negative charges		
e.g. sodium oxide	sodium ion = Na^+ oxide ion = O^{2-}	need two Na^+ ions for every one O^{2-} ions to balance charges (2+ for every 2–)	Na_2O
e.g. aluminium sulfate	aluminium ion = Al^{3+} sulfate ion = SO_4^{2-}	need three Al^{3+} ions for every two SO_4^{2-} ions to balance charges (6+ for every 6–)	$Al_2(SO_4)_3$

TASK 1a – WRITING FORMULAS OF IONIC COMPOUNDS

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

TASK 1b – FORMULAS & STRUCTURE TYPE

Name	Structure type (✓)					Formula
	Monatomic	Simple molecular	Ionic	Metallic	Giant covalent	
1) lead(IV) oxide						
2) copper						
3) sodium						
4) ammonium chloride						
5) ammonia						
6) sulfur						

Name	Structure type (✓)					Formula
	Monatomic	Simple molecular	Ionic	Metallic	Giant covalent	
7) sulfuric acid						
8) neon						
9) silica						
10) silicon						
11) barium hydroxide						
12) tin(IV) chloride						
13) silver(I) nitrate						
14) iodine						
15) nickel						
16) hydrogen sulfide						
17) titanium(IV) oxide						
18) lead						
19) strontium sulfate						
20) lithium						
21) silver(I) carbonate						
22) gold						
23) platinum(II) fluoride						
24) nitric acid						
25) ammonia						
26) silicon(IV) hydride						
27) phosphorus						
28) diamond						
29) vanadium(V) oxide						
30) cobalt(II) hydroxide						
31) barium hydroxide						
32) lithium nitride						
33) hydrochloric acid						
34) fluorine						
35) silicon						
36) calcium phosphate						
37) rubidium						
38) germanium(IV) oxide						
39) magnesium astatide						
40) nitrogen monoxide						

2 – WRITING BALANCED EQUATIONS

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

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

Some general reactions you should know:

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

TASK 2 – WRITING BALANCED EQUATIONS

1) Balance the following equations.

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

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

c) $SO_2 + O_2 \rightarrow SO_3$

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

2) Give balanced equations for the following reactions.

a) sodium + oxygen → sodium oxide

b) aluminium + chlorine → aluminium chloride

c) calcium + hydrochloric acid → calcium chloride + hydrogen

d) ammonia + sulfuric acid → ammonium sulfate

3) Write balanced equations for the following reactions:

a) burning aluminium

b) burning hexane (C_6H_{14})

c) burning ethanethiol (CH_3CH_2SH)

d) reaction of lithium with water

e) reaction of calcium carbonate with nitric acid

f) thermal decomposition of lithium carbonate

g) reaction of ammonia with nitric acid

h) reaction of potassium oxide with sulfuric acid

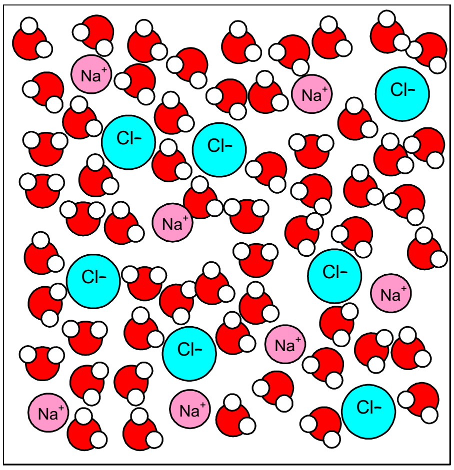
i) reaction of calcium hydroxide with hydrochloric acid

j) reaction of zinc with phosphoric acid

k) reaction of sodium hydrogencarbonate with sulfuric acid

l) reaction of potassium hydroxide with sulfuric acid

3 – WRITING 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.

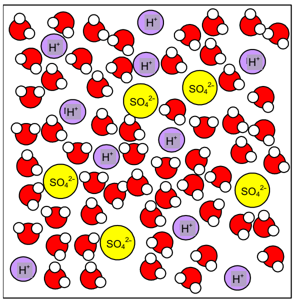
Simple examples are equations for which ionic equations can be written include:

<u>Reactions of acids:</u>

Common ionic equations **that you should know** are:

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

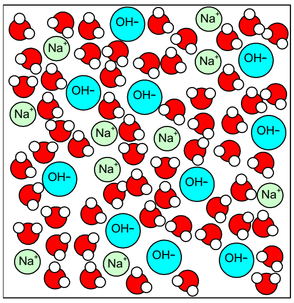
e.g. acid + hydroxide (sulfuric acid + sodium hydroxide)



H_2SO_4 (aq)

contains $H^+(aq)$

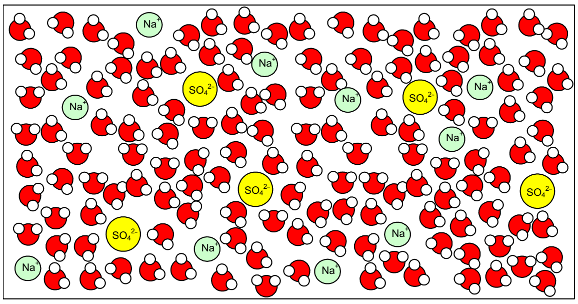
\+



NaOH (aq)

contains $OH^-(aq)$

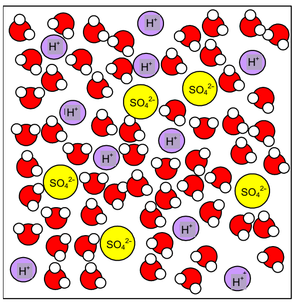
→



$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

the $Na^+(aq)$ and $SO_4^{2-}(aq)$ ions are not involved

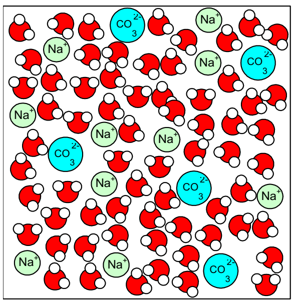
e.g. acid + carbonate (sulfuric acid + sodium carbonate)



H_2SO_4 (aq)

contains $H^+(aq)$

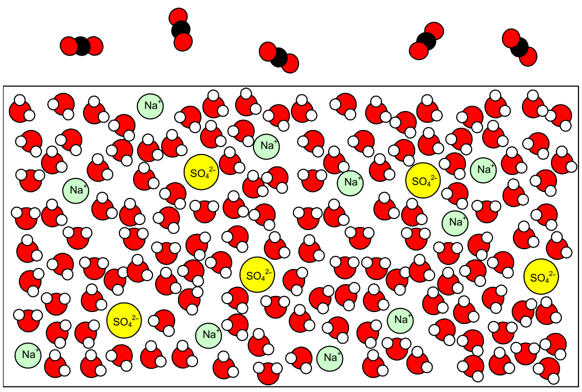
\+



Na_2CO_3 (aq)

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

→



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

the $Na^+(aq)$ and $SO_4^{2-}(aq)$ ions are not involved

When working out the ionic equation for an acid-base reaction, you simply need to decide which of the four reaction types it is.

For example:

nitric acid + potassium carbonate:	this is acid + carbonate	$\therefore$ 2 $H^+(aq) + CO_3^{2-}(aq) \rightarrow H_2O(l) + CO_2(g)$
sulfuric acid + potassium hydroxide:	this is acid + hydroxide	$\therefore$ $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

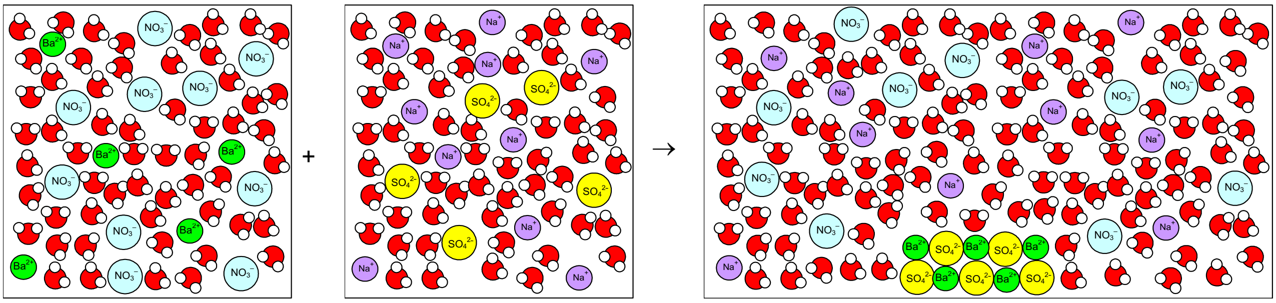
We can even use these ionic equations to work out the ratio in which acids react without writing any equation.

For example: $H_2SO_4(aq) + NaOH(aq)$

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

Precipitation reactions

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

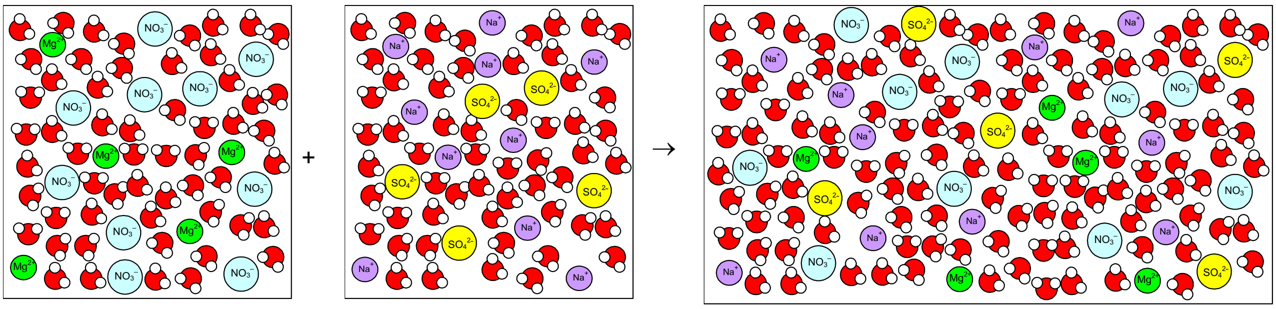


$Ba(NO_3)_2$ (aq)
contains Ba^{2+}(aq)

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

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

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



$Mg(NO_3)_2$ (aq)

Na_2SO_4 (aq)

No reaction happens – solutions just mix together (none of the combinations of ions give an insoluble compound)

When working out the ionic equation for a precipitation reaction, all you really need to do is work out the formula of the ionic precipitate formed.

For example:

precipitation of silver bromide:	$Ag^+(aq) + Br^-(aq) \rightarrow AgBr(s)$
precipitation of iron(III) hydroxide:	$Fe^{3+}(aq) + 3OH^-(aq) \rightarrow Fe(OH)_3(s)$

TASK 3 – WRITING 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.

Combination	Ionic equation	Formula of acid	Formula of base	Molar reacting ratio of acid : base
hydrochloric acid lithium hydroxide				
sulfuric acid sodium hydrogencarbonate				
nitric acid ammonia				
sulfuric acid potassium carbonate				
nitric acid strontium hydroxide				

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

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

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

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

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

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

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

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

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

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

4 – SIGNIFICANT FIGURES, ETC

Standard Form

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

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

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

Significant figures

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

- It is very important to appreciate the significance of significant figures! The integer 5 is different to 5 (1sf) or 5.0 (2sf), etc.

Number	5 (integer)	5 (1sf)	5.0 (2sf)	5.00 (3sf)
What it means	exactly 5	a number somewhere in the range 4.5 to 5.5	a number somewhere in the range 4.95 to 5.05	a number somewhere in the range 4.995 to 5.005

	Multiplication / division calculations	Addition / subtraction calculations
Guidance	Your final answer should be given to the same number of significant figures as the least number of significant figures in the data used.	Here the number of significant figures is irrelevant – it is about the place value of the data. The answer is given to the place value of the least precise number used.
Examples	**Calculate the average speed of a car that travels 1557 m in 95 seconds.** average speed = $\frac{1557}{95}$ = 16 m s^{-1} (2sf) *(answer given to 2 sf as lowest sig figs in data is 2 sf for time)* **Calculate the average speed of a car that travels 1557 m in 95.0 seconds.** average speed = $\frac{1557}{95.0}$ = 1557 = 16.4 m s^{-1} (3sf) *(answer given to 3 sf as lowest sig figs in data is 3 sf for time)*	**Calculate the total energy released when 26 kJ and 1282.3 kJ of energy are released.** Energy released = 26 + 1282.3 = 1308 kJ *(answer is to nearest unit as the least precise value used is to the nearest unit)* **Calculate the total mass of calcium carbonate when 0.154 g and 0.01234 g are mixed.** Mass = 0.154 + 0.01234 = 0.166 g *(answer is to nearest 0.001 g as the least precise value is to the nearest 0.001 g)* **Calculate the energy released from 2 moles of substance if it releases 63 kJ mol^{-1}** Energy released = 2(63) = 126 kJ *(answer is to nearest unit as the least precise value is to the nearest unit; NB as 2 is effectively an integer, we can regard this as 63 + 63)*

TASK 4 – SIGNIFICANT FIGURES, ETC

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

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

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

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

3) Write the following numbers in non-standard form.

a)	1.5×10^{-3}	…………………..	d)	5.34×10^{2}	……………………
b)	4.6×10^{-4}	…………………....	e)	1.03×10^{6}	……………………
c)	3.575×10^{5}	…………………....	f)	8.35×10^{-3}	……………………

4) Write the following numbers in standard form.

a)	0.000167	…………………..	d)	34500	……………………
b)	0.0524	…………………....	e)	0.62	……………………
c)	0.000000015	…………………....	f)	87000000	……………………

5) Complete the following calculations and give the answers to 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) $8.00 \times 10^{-3} \times 0.100 \times 10^{-3}$ …………………………………………………………….

5 – RELATIVE FORMULA MASS

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

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

TASK 5 – FORMULA MASS

Calculate the M_r of each of these substances.

1	F_2	…………………………………………
2	Fe	…………………………………………
3	H_2SO_4	…………………………………………
4	Al_2O_3	…………………………………………
5	$Mg(OH)_2$	…………………………………………
6	$Al(NO_3)_3$	…………………………………………
7	$(NH_4)_2SO_4$	…………………………………………
8	$CuCO_3$	…………………………………………
9	$AgNO_3$	…………………………………………
10	NH_4NO_3	…………………………………………
11	$CuSO_4.5H_2O$	…………………………………………
12	magnesium	…………………………………………
13	oxygen	…………………………………………
14	sodium bromide	…………………………………………
15	calcium fluoride	…………………………………………
16	potassium sulfate	…………………………………………
17	chlorine	…………………………………………
18	iron(III) nitrate	…………………………………………
19	sodium oxide	…………………………………………
20	aluminium sulfate	…………………………………………

6 – MOLES & AVOGADRO CONSTANT

- One mole of anything contains 6.022×10^{23} of those things. One mole of bananas is 6.022×10^{23} bananas. One mole of water molecules is 6.022×10^{23} water molecules
- This number is known as the Avogadro constant (= 6.022×10^{23} mol^{-1}).
- The Avogadro number was chosen so that the mass of one mole of particles of a substance equals the M_r in grams. For example, the M_r of water is 18.0, and the mass of one mole of water molecules in 18.0 grams.

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

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 6a – MOLES

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

   a) 72.0 g of Mg

   b) 4.00 kg of CuO

   c) 39.0 g of $Al(OH)_3$

   d) 1.00 tonne of NaCl

   e) 20.0 mg of $Cu(NO_3)_2$

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

   a) 5.00 moles of Cl_2

   b) 0.20 moles of Al_2O_3

   c) 0.0100 moles of Ag

   d) 0.00200 moles of $(NH_4)_2SO_4$

   e) 0.300 moles of $Na_2CO_3.10H_2O$

3) 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.

4) a) How many C atoms in one molecule of CO_2? ....

b) How many O atoms in one molecule of CO_2? ....

c) Calculate the number of moles of CO_2 molecules in 11.0 g of carbon dioxide.

....

....

d) Calculate the number of moles of C atoms in 11.0 g of carbon dioxide.

....

e) Calculate the number of moles of O atoms in 11.0 g of carbon dioxide.

....

5) a) Calculate the number of moles of Al_2O_3 in 5.10 g of Al_2O_3

....

....

b) Calculate the number of moles of Al^{3+} ions in 5.10 g of Al_2O_3

....

c) Calculate the number of moles of O^{2-} ions in 5.10 g of Al_2O_3

....

TASK 6b – THE AVOGADRO CONSTANT

1) Calculate the number of H_2O molecules in 9.0 g of water.

....

....

....

2) Calculate the number of nitrogen atoms in 42.0 g of nitrogen gas.

....

....

....

3) Calculate the mass of one ^{12}C atom in grams.

....

....

7 – EMPIRICAL & MOLECULAR FORMULA

Structure type	Monatomic	Simple molecular	Ionic	Metallic	Giant covalent
Empirical formula	✓	✓	✓	✓	✓
Molecular formula		✓			

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

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

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

- For molecular substances, the formula that is normally used (and usually called the formula) is actually the molecular formula. For other substances, the only formula that exists is the empirical formula (and is usually called the formula).

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

i) Write out the mass or percentage of each element,
ii) Divide each mass or percentage by the A_r of the element **(not the M_r)**
iii) Find the simplest whole number ratio of these numbers by dividing by the smallest number. If the values come out as near $^1/_2$'s then times them by 2, if they are near $^1/_3$'s then times by 3.

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

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

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

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

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

3 : 4 ∴ empirical formula = **Fe_3O_4**

e.g. ii) 0.25 g of hydrogen reacts with oxygen to produce 4.25 g of a compound. Determine its empirical formula.

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

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

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

1 : 1 ∴ empirical formula = **HO**

b) Finding the molecular formula for a molecular compound from the M_r and empirical formula

e.g. Find the molecular formula of a compound with empirical formula = CH_2 and M_r = 42.0

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

Molecular formula = 3 x empirical formula = C_3H_6

TASK 7 – 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) State 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)	C	2.73 g	O	7.27 g		
c)	Na	29.1 %	S	40.5 %	O	30.4 %
d)	N	15.2 g	O	34.8 g		
e)	C	53.3 %	H	15.5 %	N	31.1 %

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.

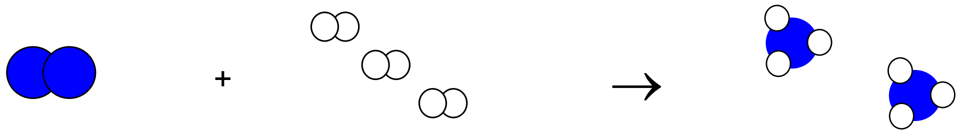
7) An oxide of phosphorus contains 56.4 % phosphorus and 43.6 % oxygen. Its relative molecular mass is 220. Find both the empirical and the molecular formula of the oxide.

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 – REACTING RATIOS



N_2	+	$3\ H_2$	→	$2\ NH_3$
1 molecule N_2		3 molecules H_2		2 molecules NH_3
12 molecules N_2 1 dozen molecules N_2		36 molecules H_2 3 dozen molecules H_2		24 molecules NH_3 2 dozen molecules NH_3
12 molecule N_2 1 dozen molecules N_2		36 molecules H_2 3 dozen molecules H_2		24 molecules NH_3 2 dozen molecules NH_3
6×10^{23} molecule N_2 1 mole N_2		18×10^{23} molecules H_2 3 moles H_2		12×10^{23} molecules NH_3 2 moles NH_3
10 moles N_2		30 moles H_2		20 moles NH_3
0.5 moles N_2		1.5 moles H_2		1 mole NH_3

TASK 8 – REACTING RATIOS

4 Na	**+**	**O_2**	**→**	**$2\ Na_2O$**		
12 mol						
0.1 mol						

2 Al	**+**	**$3\ Cl_2$**	**→**	**$2\ AlCl_3$**		
5 mol						
0.1 mol						

C_4H_{10}	**+**	**$6\frac{1}{2}\ O_2$**	**→**	**$4\ CO_2$**	**+**	**$5\ H_2O$**
0.5 mol						
20 mol						

$4\ NH_3$	**+**	**$3\ O_2$**	**→**	**$2\ N_2$**	**+**	**$6\ H_2O$**
0.5 mol						
10 mol						

9 – REACTING MASS CALCULATIONS

- You can use balanced chemical equations to find out quantities of chemicals that react or are produced in a chemical reaction. To do this:
  - list the information given under those substances (it may be helpful to out a ? above the substance whose quantity you are calculating)
  - calculate the moles of the substance with most information
  - calculate the moles of the substance whose quantity you are calculating
  - calculate the mass (or volume for gas/solution) of the substance whose quantity you are calculating

e.g. What mass of iron is produced when 32.0 kg of iron(III) oxide is heated with CO?

$$\underset{32.0\text{ kg}}{Fe_2O_3(s)} + 3\,CO(g) \rightarrow \overset{?}{2\,Fe(s)} + 3\,CO_2(g)$$

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

1 mole of Fe_2O_3 forms 2 moles of Fe

∴ moles of Fe = 2 x 200.5 = 401.0 mol

∴ mass of Fe = moles x M_r = 401.0 x 55.8 = **22,400 g (3 sf)**

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

$$\underset{102\text{ g}}{4\,NH_3(g)} + \overset{?}{3\,O_2(g)} \rightarrow 2\,N_2(g) + 6\,H_2O(g)$$

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

4 moles of NH_3 reacts with 3 moles of O_2 ∴ 1 mole of NH_3 reacts with ¾ mole of O_2

∴ moles of O_2 = 6.00 x ¾ = 4.50 mol

∴ mass of O_2 = moles x M_r = 4.50 x 32.0 = **144 g (3 sig fig)**

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

$$\underset{5.00\text{ g}}{SnCl_2.xH_2O} \rightarrow \underset{4.20\text{ g}}{SnCl_2} + x\,H_2O$$

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

∴ moles of $SnCl_2.xH_2O$ = 0.02214 mol

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

∴ M_r of xH_2O = 225.8 – 189.7 = 36.1

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

TASK 9a – SIMPLE REACTING MASS CALCULATIONS

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

   $CuO + H_2 \rightarrow Cu + H_2O$

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

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

3) What mass of sulfur trioxide is formed from 96.0 g of sulfur dioxide?

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

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

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

5) What mass of carbon dioxide is produced when 5.60 g of butene is burnt.

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

6) What mass of oxygen is needed to react with 8.50 g of hydrogen sulfide (H_2S)?

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

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

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

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

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

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

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

10) The pollutant sulfur dioxide can removed from the air by reaction with calcium carbonate in the presence of oxygen. What mass of calcium carbonate is needed to remove 1.000 tonnes of sulfur dioxide?

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

11) What mass of potassium oxide is formed when 7.80 mg of potassium is burned in oxygen?

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

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

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

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

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

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

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

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

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

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

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

Limiting reagents

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

e.g. Propane reacts with oxygen as shown: $C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$

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

	C_3H_8	+	$5\ O_2$	$\rightarrow$	$3\ CO_2$	+	$4\ H_2O$
I nitial moles	1 mol		8 mol				
C hange in moles	1 mol react		5 mol react		3 mol made		4 mol made
E nd moles	1 – 1 = 0 mol		8 – 5 = 3 mol		0 + 3 = 3 mol		0 + 4 = 4 mol
	C_3H_8 limiting reagent		O_2 in excess				

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

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

	$2\ SO_2$	+	O_2	$\rightarrow$	$2\ SO_3$
I nitial moles	5 mol		2 mol		
C hange in moles	4 mol react		2 mol react		4 mol made
E nd moles	5 – 4 = 1 mol		2 – 2 = 0 mol		0 + 4 = 4 mol
	SO_2 in excess		O_2 limiting reagent		

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

e.g. In the manufacture of titanium, what mass of titanium can theoretically be formed when 1000 g of titanium chloride reacts with 200 g of magnesium?

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

	$TiCl_4$	+	$2\ Mg$	$\rightarrow$	**Ti**	+	$2\ MgCl_2$
I nitial moles	$\frac{1000}{189.9}$ = 5.266 mol		$\frac{200}{24.3}$ = 8.230 mol				
	5.266 moles of $TiCl_4$ needs 10.53 moles of Mg to react						
	∴ $TiCl_4$ is in excess and does not all react, so Mg is the limiting reagent						
	∴ 8.230 mol of Mg reacts with 4.115 mol of $TiCl_4$						
C hange in moles	4.115 mol reacts		8.230 mol reacts		4.115 mol made		8.230 mol made
E nd moles					0 + 4.115 = 0.4115 mol		

∴ Mass of Ti = M_r x 4.115 = 47.9 x 4.115 = **197 g (3sf)**

TASK 9b – LIMITING REAGENTS 1

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

TASK 9c – LIMITING REAGENTS 2

1 What mass of calcium hydroxide is formed when 10.0 g of calcium oxide reacts with 10.0 g of water?

$CaO + H_2O \rightarrow Ca(OH)_2$

2 What mass of magnesium bromide is formed when 1.00 g of magnesium reacts with 5.00 g of bromine?

$Mg + Br_2 \rightarrow MgBr_2$

3 What mass of copper is formed when 2.00 g of copper(II) oxide reacts with 1.00 g of hydrogen?

$CuO + H_2 \rightarrow Cu + H_2O$

4 What mass of sodium fluoride is formed when 2.30 g of sodium reacts with 2.85 g of fluorine?

$2Na + F_2 \rightarrow 2NaF$

5 What mass of iron is formed when 8.00 g of iron(III) oxide reacts with 2.16 g of aluminium?

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

6 What mass of aluminium chloride is formed when 13.5 g of aluminium reacts with 42.6 g of chlorine?

$2Al + 3Cl_2 \rightarrow 2AlCl_3$

7 5.00 g of iron and 5.00 g of sulfur are heated together to form iron(II) sulfide. Which reactant is in excess and what is the maximum mass of iron(II) sulfide that can be formed?

$Fe + S \rightarrow FeS$

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

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

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

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

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

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

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

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

12 In the manufacture of sulfur trioxide, what mass of sulfur trioxide can theoretically be formed when 1.00 kg of sulfur dioxide reacts with 0.320 kg of oxygen?

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

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

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

10 – 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)
V = volume (m^3)
n = number of moles
R = gas constant (8.31 J mol^{-1} K^{-1})
T = temperature (K)

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

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

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

TASK 10 – THE IDEAL GAS EQUATION

1) Convert the following into SI units.
   a) 200ºC b) 98 kPa c) 50 cm^3 d) –50ºC e) 0.1 MPa f) 3.2 dm^3
2) Calculate the volume that 0.400 moles of an ideal gas occupies at 373 K and a pressure of 1.00 x 10^3 kPa
3) How many moles of gas occupy 19400 cm^3 at 27.0ºC and 101 kPa pressure?
4) Calculate the pressure that 0.0500 moles of gas, which occupies a volume of 2.00 x 10^2 cm^3 exerts at a temperature of 68 K
5) 0.140 moles of a gas has a volume of 2.00 dm^3 at a pressure of 90.0 kPa. Calculate the temperature of the gas.
6) At 273 K and 101000 Pa, 6.319 g of a gas occupies 2.00 dm^3. Calculate the relative molecular mass of the gas.
7) Find the volume of ethyne (C_2H_2) that can be prepared from 10.0 g of calcium carbide at 20.0ºC and 1.00 x 10^2 kPa
   $CaC_2(s) + 2\ H_2O(l) \rightarrow Ca(OH)_2(aq) + C_2H_2(g)$
8) Find the volume of gas formed when 1.00 g of strontium nitrate decomposes at 1.01 x 10^2 kPa and 525ºC
   $2\ Sr(NO_3)_2(s) \rightarrow 2\ SrO(s) + 4\ NO_2(g) + O_2(g)$
9) What mass of potassium chlorate(V) must be heated to give 1.00 dm^3 of oxygen at 20.0ºC and 0.100 MPa
   $2\ KClO_3(s) \rightarrow 2\ KCl(s) + 3\ O_2(g)$
10) What volume of hydrogen gas, measured at 298 K and 101 kPa, is produced when 1.0 g of sodium is reacted with excess water?
    $2\ Na(s) + 2\ H_2O(l) \rightarrow 2\ NaOH(aq) + H_2(g)$
11) What volume of carbon dioxide gas, measured at 805 K and 98 kPa, is formed when 1.00 kg of propane is burned in a good supply of oxygen?
    $C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$
12) Calculate the relative molecular mass of a gas which has a density of 2.615 g dm^{-3} at 298 K and 101 kPa.
13) A certain mass of an ideal gas is in a sealed vessel of volume 3.25 dm^3. At a temperature of 25.0ºC it exerts a pressure of 101 kPa. What pressure will it exert at 100ºC?
14) An ideal gas occupies a volume of 2.75 dm^3 at 295K and 8.70 x 10^4 Pa. At what temperature will it occupy 3.95 dm^3 at 1.01 x 10^5 Pa?

11 – REACTING GAS VOLUMES

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

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

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

Answer = 600 cm^3

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

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

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

TASK 11 – REACTING GAS VOLUMES

In each of these questions, assume that the volumes of all gases are measured at the same temperature and pressure.

1 Propane burns in oxygen: $C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l)$

50 cm^3 of propane is mixed with 600 cm^3 of oxygen. The oxygen is an excess.

a What volume of oxygen reacts with the 50 cm^3 of propane? ....

b What volume of carbon dioxide is formed? ....

c What is the total volume of gases left at the end? ....

2 Butane burns in oxygen: $2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(l)$

100 cm^3 of butane is mixed with 800 cm^3 of oxygen. The oxygen is an excess.

a What volume of oxygen reacts with the 100 cm^3 of butane? ....

b What volume of carbon dioxide is formed? ....

c What is the total volume of gases left at the end? ....

3 Phosphorus trichloride reacts with chlorine to make phosphorus pentachloride: $PCl_3(g) + Cl_2(g) \rightarrow PCl_5(g)$

2.0 dm^3 of phosphorus trichloride is mixed with 1.5 dm^3 of chlorine. Calculate the total volume of gases after the reaction has completed. Show your working clearly.

....

....

....

4 Methane burns in oxygen: $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$

250 cm^3 of methane is mixed with 800 cm^3 of oxygen. Calculate the total volume of gases after the reaction has completed. Show your working clearly.

....

....

....

5 Hydrogen sulfide reacts with oxygen: $2\ H_2S(g) + 3\ O_2(g) \rightarrow 2\ H_2O(g) + 2\ SO_2(g)$

4 dm^3 of hydrogen sulfide is burned in 10 dm^3 of oxygen. What is the final volume of the mixture? Show your working clearly.

....

....

....

6 Fluorine reacts with oxygen: $2F_2(g) + O_2(g) \rightarrow 2F_2O(g)$

100 cm^3 of fluorine is mixed with 40 cm^3 of oxygen. Calculate the total volume of gases after the reaction has completed. Show your working clearly.

....

....

....

7 Hydrogen sulfide reacts with oxygen when heated: $2H_2S(g) + 3O_2(g) \rightarrow 2SO_2(g) + 2H_2O(g)$

600 cm^3 of hydrogen sulfide is mixed with 600 cm^3 of oxygen. Calculate the total volume of gases after the reaction has completed. Show your working clearly.

....

....

....

8 Ammonia reacts with oxygen when heated: $4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g)$

500 cm^3 of ammonia is mixed with 1000 cm^3 of oxygen. Calculate the total volume of gases after the reaction has completed. Show your working clearly.

....

....

....

9 100 cm^3 of a gaseous hydrocarbon C_nH_{2n} undergoes complete combustion in 800 cm^3 of oxygen (an excess) to give gaseous carbon dioxide and liquid water. There are 600 cm^3 of gas at the end of the reaction. Determine the formula of the hydrocarbon.

....

....

....

....

....

....

12 – PERCENTAGE YIELD

1) When you make a new substance by a chemical reaction, you may not get all the expected amount of product. For example, if you react 4 g of hydrogen with 32 g of oxygen, you may get less than the expected 36 g of water.
2) Reasons include why the yield is less than 100% when someone does a reaction include:
   - the reaction may be reversible (both the forwards and backwards reaction can take place)
   - the reaction is incomplete
   - some of the product may be lost when it is separated from the reaction mixture
   - some of the reactants may react in other reactions

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

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

a) Calculate the maximum theoretical mass of tungsten that can be made from 500 g of tungsten(VI) oxide.

Moles of WO_3 = $\frac{\text{mass (g)}}{M_r} = \frac{500}{231.8} = 2.157$ mol

∴ moles of W = 2.157 mol

∴ mass of W = M_r x moles = 183.8 x 2.157 = **396 g**

b) In the reaction, only 350 g of tungsten was made. Calculate the percentage yield.

% Yield = $\frac{\text{mass of product obtained}}{\text{maximum theoretical mass of product}} \ x\ 100 = \frac{350}{396} \ x\ 100$ = **88.3%**

TASK 12 – PERCENTAGE YIELD

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

a) Calculate the maximum theoretical mass of sulfur trioxide that can be made by reacting 96.0 g of sulfur dioxide with an excess of oxygen.

b) In the reaction, only 90.0 g of sulfur trioxide was made. Calculate the percentage yield.

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

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

a) Calculate the maximum theoretical mass of iron that can be made from reaction of 1.00 tonne of iron(III) oxide with an excess of carbon monoxide.

b) In the reaction, only 0.650 tonnes of iron was made. Calculate the percentage yield.

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

a) Determine the limiting reagent and then calculate the maximum theoretical mass of ammonia that can be made by reacting 90.0 g of hydrogen with 225 g of nitrogen.

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

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

a) Determine the limiting reagent and then calculate the maximum theoretical mass of titanium that can be extracted from 102 g of titanium chloride reacting with 20.5 g of magnesium.

b) In the reaction, only 18.0 g of titanium was made. Calculate the percentage yield.

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

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

a) Calculate the maximum theoretical mass of aluminium that can be made from 1.00 kg of aluminium oxide.

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

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

a) Calculate the maximum theoretical mass of ammonium sulfate that can be made by reacting 85.0 g of ammonia with an excess of sulfuric acid.

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

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

13 – 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.

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

e.g. making ethanol by fermentation

glucose		ethanol		carbon dioxide
$C_6H_{12}O_6(aq)$	$\rightarrow$	$2\ CH_3CH_2OH(aq)$	+	$2\ CO_2$
180 g		92 g		88 g

$\underbrace{92\text{ g} \quad 88\text{ g}}_{180\text{ g products}}$

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

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

TASK 13 – ATOM ECONOMY

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

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

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

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

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

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

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

ammonia + sodium chlorate → hydrazine + sodium chloride + water

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

a) Calculate the maximum theoretical mass of hydrazine that can be made by reacting 347 g of ammonia with an excess of sodium chlorate.

b) In the reaction, only 282 g of hydrazine was produced. Calculate the percentage yield.

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

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

Should I get a Health Checkup?

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

a) zinc(II) nitrate …………………

b) lead …………………

c) chromium(III) oxide …………………

d) ammonium sulfate …………………

e) phosphorus ………………………

f) nitrogen ………………………

g) barium hydroxide ………………………

h) aluminium sulfate ……………………… (8)

2) Use your knowledge of ionic equations to give the molar ratio in which the following acids react with bases. Complete the table to show your answers. (4)

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

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

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

……… (2)

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

……… (2)

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

……… (2)

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

……… (2)

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

……… (2)

b) Explain why the relative atomic mass of ^{12}C atoms is exactly 12. …………………………………………….

……… (1)

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

……… (1)

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

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

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

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

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

d) 0.200 moles of N_2 + 0.0500 moles of H_2 moles of NH_3 formed = ………….. (1)

6) Calculate the volume of 0.200 moles of carbon dioxide at 100°C and 2.00 MPa pressure.

………

………

………

……… (3)

7) Calculate the number of moles of argon in 205 cm^3 at 101 kPa at 20.0°C

………

………

………

……… (3)

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

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

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

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

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

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

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

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

9) What volume of hydrogen is formed at 21°C and 1.0×10^5 Pa pressure when 2.00 g of magnesium is reacted with excess sulfuric acid?

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

………

………

………

……… (4)

10) What volume of carbon monoxide is formed at 1205°C and 0.140 MPa pressure when 1.00 kg of iron(III) oxide is reduced by carbon?

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

………

………

………

……… (4)

11) a) In 20 moles of Al_2O_3,

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

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

b) In 360 g of water

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

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

c) In 1.00 kg of aluminium sulfate

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

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

12) What mass of Fe_3O_4 is produced when 14 g of iron reacts with excess steam?

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

………

………

……… (3)

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

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

………

………

……… (3)

14) a) Sulfur trioxide is made from sulfur dioxide by the following reaction. Calculate the maximum amount of sulfur trioxide that can be made from 1.00 kg of sulfur dioxide.

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

………

………

……… (3)

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

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

……… (1)

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

………

………

……… (3)

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

15) a) Aluminium is made from aluminium oxide by electrolysis. Calculate the mass of aluminium that can be made from 1.00 kg of aluminium oxide.

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

………

………

……… (3)

b) Calculate the percentage yield if 502 g of aluminium is produced.

……… (1)

c) Calculate the percentage atom economy for this process.

……… (1)

16) When 12.30 g of $MgSO_4.nH_2O$ is heated gently until no further change in mass occurs, to remove the water of crystallisation, 6.00 g of anhydrous magnesium sulfate ($MgSO_4$) remained. Work out the relative formula mass (M_r) of the $MgSO_4.nH_2O$, and so the value of *n*.

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

………

………

………

………

……… (4)

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

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

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

The total moisture content of a book which was treated was found to be 0.900 g of water.

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

……… (1)

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

……… (1)

iii) What is the volume at 293 K and 101 kPa of this amount of diethyl zinc vapour?

………

………

……… (3)

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

……… (2)

b) The acid content of the book was found to be 0.0320 moles of $H^+(aq)$. The equation for the reaction between zinc(II) oxide and acid is:

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

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

……… (2)

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

………

……… (2)

14 – SOLUTION CALCULATIONS & TITRATIONS

Concentration of solutions (mol dm^{-3})

- The concentration of solutions is usually measured in mol dm^{-3}

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

- There are 1000 cm^3 in 1 dm^3 and so volume in dm^3 = $\frac{\text{volume in cm}^3}{1000}$

e.g. 0.0500 mol of NaOH dissolved in 25.0 cm^3 of solution   concentration of NaOH = $\frac{0.0500}{\frac{25.0}{1000}}$ = 2.0 mol dm^{-3}

Concentration of solutions (g dm^{-3})

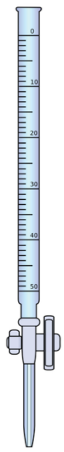
- Concentration is sometimes measured in g dm^{-3}

$$\text{concentration (g dm}^{-3}) = M_\text{r} \text{ x concentration (mol dm}^{-3})$$

Titrations

- A titration is a very accurate experiment where:
  - a precisely measured volume of one solution is placed in a conical flask using a pipette (often 25.0 cm^3)
  - an indicator is added
  - a second solution added from a burette until the precise moment at which the indicator shows all the first solution has reacted; the volume of the second solution can be read from the burette

- Many titrations involve an acid reacting with a base (acid-base titration). Titrations involving redox reactions are also done (redox titrations).
- In many titrations, a solution of one the reagents is made in a volumetric flask (typically 250 cm^3) and 25 cm^3 portions of this solution are used in each titration.



burette

pipette

Titration calculations

i) list the information given under those substances (it may be helpful to out a ? above the substance whose quantity you are calculating)

ii) calculate the moles of the substance with most information

iii) calculate the moles of the substance whose quantity you are calculating (use the reacting ratio – see table below)

iv) calculate the volume / concentration / mass (i.e. whatever you have been asked) of the substance whose quantity you are calculating

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

E.g. 1: 25.00 cm^3 of 0.020 mol dm^{-3} sulfuric acid neutralises 18.60 cm^3 of sodium hydroxide solution.

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

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

moles of H_2SO_4 = conc x vol (dm^3) = $0.020\ x\ \frac{25.00}{1000}$ = 0.000500

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

concentration of NaOH = $\frac{\text{moles}}{\text{volume }(\text{dm}^3)}$ = $\frac{0.00100}{\frac{18.60}{1000}}$ = **0.0538 mol dm^{-3}**

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

M_r of NaOH = 23.0 + 16.0 + 1.0 = 40.0

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

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

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

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

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

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

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

M_r of nH_2O = 209.2 – 192.0 = 17.2

n = $\frac{17.2}{18.0}$ = 0.954 = **1 (n is a whole number)**

TASK 14a – TITRATION CALCLATIONS 1

1) Calculate the number of moles in the following.
   a) 2.00 dm^3 of 0.0500 mol dm^{-3} HCl
   b) 50.0 cm^3 of 5.00 mol dm^{-3} H_2SO_4
   c) 10.00 cm^3 of 0.250 mol dm^{-3} KOH

2) Calculate the concentration of the following in mol dm^{-3}
   a) 0.00400 moles of HCl in 25.00 cm^3 of solution
   b) 12.5 moles of H_2SO_4 in 5.00 dm^3 of solution
   c) 1.05 g of NaOH in 500.0 cm^3 of solution

3) Calculate the volume of each solution that contains the following number of moles.
   a) 0.0050 moles of NaOH from 0.100 mol dm^{-3} solution
   b) 1.00 x 10^{-5} moles of HCl from 0.0100 mol dm^{-3} solution

4) 25.00 cm^3 of 0.0200 mol dm^{-3} nitric acid neutralises 18.60 cm^3 of barium hydroxide solution.

$$2\,HNO_3 + Ba(OH)_2 \rightarrow BaSO_4 + 2\,H_2O$$

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

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

5) 25.00 cm^3 of a solution of sulfuric acid required 18.80 cm^3 of 0.0500 mol dm^{-3} sodium hydroxide. Find the concentration of the sulfuric acid solution in mol dm^{-3}

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

6) Calculate the volume of 0.0500 mol dm^{-3} KOH is required to neutralise 25.00 cm^3 of 0.0150 mol dm^{-3} HNO_3.

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

7) 25.00 cm^3 of arsenic acid, H_3AsO_4, required 37.55 cm^3 of 0.100 mol dm^{-3} sodium hydroxide for neutralisation.

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

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

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

8) A 250.0 cm^3 volumetric solution of NaOH was prepared. 25.00 cm^3 of this solution required 28.25 cm^3 of 0.100 mol dm^{-3} HCl for neutralisation. Calculate what mass of NaOH was dissolved to make up the original 250 cm^3 solution.

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

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

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

10) 3.88 g of a monoprotic acid was dissolved in water and the solution made up to 250 cm^3 in a volumetric flask. 25.00 cm^3 of this solution was titrated with 0.0950 mol dm^{-3} NaOH solution, requiring 46.53 cm^3. Calculate the relative molecular mass of the acid.

11) A 1.575 g sample of ethanedioic acid crystals, $H_2C_2O_4.nH_2O$, was dissolved in water and made up to 250 cm^3 in a volumetric flask. Ethanedioic acid is a diprotic acid. In a titration, 25.00 cm^3 of this solution of acid reacted with exactly 15.60 cm^3 of 0.160 mol dm^{-3} NaOH. Calculate the value of *n*.

12) A solution of a metal carbonate, M_2CO_3, was prepared by dissolving 7.46 g of the anhydrous solid in water to give 1000 cm^3 of solution. 25.00 cm^3 of this solution reacted with 27.03 cm^3 of 0.100 mol dm^{-3} hydrochloric acid. Calculate the relative formula mass of M_2CO_3 and hence the relative atomic mass of the metal M.

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).
- In a back titration,
  - the base (or acid) being analysed 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).

For example

- imagine that we are trying to find out how many moles of $CaCO_3$ we have be doing a back titration.
- we add 10 moles of HCl (an excess) to the $CaCO_3$ ($CaCO_3 + 2\ HCl \rightarrow CaCl_2 + H_2O + CO_2$)
- the excess HCl is made into a 250 cm^3 solution in a volumetric flask
- 25 cm^3 portions of this volumetric solution of excess HCl are titrated against NaOH using 0.4 moles of NaOH for neutralisation ($HCl + NaOH \rightarrow NaCl + H_2O$)
  - this means that 0.4 mol of HCl is reacting in each titration
  - therefore there is 10 x 0.4 mol (= 4 mol) of left over HCl in the volumetric flask solution (as we used 1/10th of the solution in the volumetric flask in each titration)
  - as we added 10 mol of HCl to the $CaCO_3$ at the start and there was 4 mol of HCl left over, then 6 mol of HCl reacted with the $CaCO_3$
  - this means that there must have been 3 moles of $CaCO_3$ in the first place (remember that 2 mol of HCl reacts with 1 mol of $CaCO_3$).

TASK 14b – BACK TITRATION CALCLATIONS

1 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 some aspirin and make the resulting solution into a 250 cm^3 stock solution. We titrate 25 cm^3 portions of the solution which require 0.01 moles of HCl for neutralisation. Calculate the original moles of aspirin.

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

3 A sample of magnesium carbonate was analysed. Calculate (a) the moles and (b) the mass of magnesium carbonate at the start if 0.200 moles of sulfuric acid is added to the magnesium carbonate and the excess sulfuric acid made up to a 250 cm^3 solution. 25.0 cm^3 of this solution required 0.0300 moles of sodium hydroxide for neutralisation.

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

4 Limestone is mainly calcium carbonate. A student wanted to find what percentage of some limestone was calcium carbonate. A 1.00 g sample of limestone is allowed to react with 100 cm^3 of 0.200 mol dm^{-3} HCl. The excess acid required 24.80 cm^3 of 0.100 mol dm^{-3} NaOH solution in a back titration. Calculate the percentage of calcium carbonate in the limestone.

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

5 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 (25.00 cm^3 of 1.00 mol dm^{-3}). She made the excess acid up to 250 cm^3 by adding water in a volumetric flask. She then titrated 25 cm^3 samples of this volumetric solution against 0.0500 mol dm^{-3} NaOH requiring 25.78 cm^3 of the NaOH. Calculate the mass of calcium carbonate in the tablet.

6 An impure sample of barium hydroxide of mass 1.6524 g was allowed to react with 50.0 cm^3 of 0.400 mol dm^{-3} hydrochloric acid. Water was added to the excess acid to make 250 cm^3 solution in a volumetric flask. 25.0 cm^3 portions of this solution was titrated against 0.0228 mol dm^{-3} sodium hydroxide in a back titration with 10.90 cm^3 of sodium hydroxide solution was required. Calculate the percentage purity of the sample of barium hydroxide.

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

7 A sample containing ammonium chloride was warmed with 100.0 cm^3 of 1.00 mol dm^{-3} sodium hydroxide solution. After the ammonia had reacted the excess sodium hydroxide required 50.00 cm^3 of 0.250 mol dm^{-3} HCl for neutralisation. What mass of ammonium chloride did the sample contain?

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 178.0 by mass spectroscopy. Find its empirical and molecular formulae.

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

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

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

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

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

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

6) 25.00 cm^3 of 0.0400 mol dm^{-3} sodium hydroxide solution reacted with 20.75 cm^3 of sulfuric acid in a titration. Find the concentration of the sulfuric acid.

7) 13.80 g of a solid monoprotic acid was dissolved in water and made up to 250.0 cm^3. 25.00 cm^3 portions of this were titrated against 0.2500 mol dm^{-3} sodium hydroxide, requiring 23.50 cm^3. Calculate the M_r of the acid.

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

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

The resulting solution was filtered to remove unreacted copper and then made up to 250 cm^3 with water. 25.0 cm^3 of this solution was found to neutralise 36.80 cm^3 of 0.200 mol dm^{-3} NaOH. Find the % by mass of the magnesium in the metal powder mixture.

9) 12.0 g of a mixture of calcium carbonate and sodium chloride was treated with 100 cm^3 of 2.00 mol dm^{-3} hydrochloric acid (only the calcium carbonate reacts). The resulting solution was made up to 250 cm^3 with water and a 25.0 cm^3 portion of this needed 34.10 cm^3 of 0.200 mol dm^{-3} sodium hydroxide for neutralisation. Find the % by mass of the calcium carbonate in the mixture.

10) The solid booster rockets of the NASA Space Shuttle were fuelled by a mixture of aluminium and ammonium chlorate(VII) (NH_4ClO_4).

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

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

1 10.00 g of a mixture of anhydrous sodium carbonate and sodium hydrogencarbonate was heated until it reached a constant mass of 8.708 g. Calculate the % by mass of sodium hydrogencarbonate in the original mixture. [Sodium hydrogencarbonate thermally decomposes to form sodium carbonate, but sodium carbonate is thermally stable.]

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. Find the mass of calcium carbonate in the mixture.

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 0.50 dm^3 of a gaseous alkane C_nH_{2n+2} undergoes complete combustion with 6.25 dm^3 of oxygen. Give the molecular formula of the alkane.

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

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

$2\ NaN_3(s) \rightarrow 2\ Na(s) + 3\ N_2(g)$ $\qquad$ $10\ Na(s) + 2\ KNO_3(s) \rightarrow K_2O(s) + 5\ Na_2O(s) + N_2(g)$

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

b Calculate the total mass of the solid mixture needed to inflate a 60.0 dm^3 air bag at 298 K and 101 kPa.

7 1.00 g of sulfur dissolved completely in an excess of liquid ammonia to give 420 cm^3 of hydrogen sulfide (H_2S), measured at 273 K and 101 kPa, and also a solid containing the elements nitrogen and sulfur. Deduce the empirical formula of the solid.

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

9 A fertiliser contains ammonium sulfate and potassium sulfate. A sample of 1.455 g of the fertiliser was warmed with 25.0 cm^3 0.200 mol dm^{-3} sodium hydroxide solution giving off ammonia gas. The remaining NaOH that was not used required 28.70 cm^3 of 0.100 mol dm^{-3} hydrochloric acid for neutralisation. Calculate the percentage by mass of ammonium sulfate in the sample.

10 Silicon tetrachloride dissolves in ethoxyethane, an inert solvent. If the ethoxyethane is contaminated with a little water, a partial hydrolysis occurs and two compounds **A** and **B** are formed.

The formula of **A** is Si_2OCl_6 and that of **B** is $Si_3O_2Cl_8$

When a 0.100 g sample of one of the compounds, **A** or **B** reacted with an excess of water, all the chlorine present was converted to chloride ions.

Titration of this solution with aqueous silver(I) nitrate, in the presence of a suitable indicator, required 42.10 cm^3 of 0.0500 mol dm^{-3} aqueous silver(I) nitrate for complete precipitation of silver(I) chloride.

Deduce which of the compounds **A** or **B** was present in the 0.100 g sample.

ANSWERS

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TASK 4 – SIGNIFICANT FIGURES, ETC

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	1.64×10^{-4}	b	5.24×10^{-2}	c	1.5×10^{-8}	d	3.45×10^{4}	e	6.2×10^{-1}	f	8.7×10^{7}
5	a	0.021 (2sf)	b	6.1×10^{-5} (2sf)	c	4.0×10^{8}	d	2400	e	0.0610	f	8.00×10^{-7} (3sf)

TASK 5 – FORMULA MASS

1	38.0	8	123.5	15	78.1
2	55.8	9	169.9	16	174.3
3	98.1	10	80.0	17	71.0
4	102.0	11	249.6	18	296.1
5	58.3	12	24.3	19	62.0
6	213.0	13	32.0	20	342.5
7	132.1	14	102.9		

TASK 6a – MOLES

1) a) 2.96 (3sf)
   b) 50.3 (3sf)
   c) 0.500 (3sf)
   d) 17100 (3sf)
   e) 1.07×10^{-4} (3sf)

2) a) 355 g (3sf)
   b) 20 g (2sf)
   c) 1.08 g (3sf)
   d) 0.264 g (3sf)
   e) 85.8 g (3sf)

3) 176 (3sf)

4) a) one C atom
   b) two O atoms
   c) 0.250 (3sf)
   d) 0.250 (3sf)
   e) 0.500 (3sf)

5) a) 0.0500 (3sf)
   b) 0.100 (3sf)
   c) 0.150 (3sf)

TASK 6b – THE AVOGADRO CONSTANT

1) 3.0×10^{23} (2sf)
2) 1.81×10^{24} (3sf)
3) 1.993×10^{-23} g (4sf)

TASK 7 – EMPIRICAL & MOLECULAR FORMULAS

1 a CH_3 b P_2O_3 c SO_2 d CH_2
  e CH_2O f C_2H_7N g B_3H_5 h $C_{12}H_{22}O_{11}$

2 a N_2H_4 b C_4H_{10} c C_5H_{10} d PH_3 e C_6H_6 f C_3H_6

3 a 3:2 b 1:2 c 5:1 d 2:5
  e 3:4 f 5:3 g 4:5 h 4:7

4 a $CaBr_2$
  b CO_2
  c $Na_2S_2O_3$
  d NO_2
  e C_2H_7N

5 $FeCl_3$

6 K_2SO_4

7 Empirical formula = P_2O_3 Molecular formula = P_4O_6

8 Empirical formula = CH_2O Molecular formula = $C_5H_{10}O_5$

9 Empirical formula = $C_5H_{10}O$ Molecular formula = $C_5H_{10}O$

10 s = 4 and y = 2

TASK 8 – REACTING RATIOS

3 mol	6 mol	
0.025 mol	0.05 mol	
7.5 mol	5 mol	
0.15 mol	0.1 mol	
3.25 mol	2 mol	2.5 mol
130 mol	80 mol	100 mol
0.375 mol	0.25 mol	0.75 mol
7.5 mol	5 mol	15 mol

TASK 9a – REACTING MASS CALCULATIONS

1) 1.0 g (2 sf)
2) 126 g (3 sf)
3) 120 g (3 sf)
4) 253000 g (3 sf)
5) 17.6 g (3 sf)
6) 12.0 g (3 sf)
7) 7 (integer)
8) 6 (integer)
9) 9780 g (3 sf)
10) 1.56×10^{6} g (3 sf)
11) 9.40×10^{-3} g (3 sf)
12) 1.11 g (3 sf)
13) 115 g (3 sf)
14) 1.65×10^{6} g (3 sf)
15) 64.0 g (3 sf)
16) 89.3 g (3 sf)

TASK 9b – LIMITING REAGENTS 1

1) 2, 8, 0.4 mol
2) 2, 4, 0.4 mol
3) 2, 10, 20 mol
4) 1, 4   2, 8   0.25, 1.0 mol
5) 20, 30   0.5, 0.75   4, 6 mol
6) 4, 0.6, 12 mol
7) 4, 3, 0.25 mol

TASK 9c – LIMITING REAGENTS 2

1) 13.23 g (3sf)
2) 5.76 g (3sf)
3) 1.60 g (3 sf)
4) 4.20 g (3 sf)
5) 4.46 g (3 sf)
6) 53.4 g (3sf)
7) 7.88 g (3sf)
8) 2690 g (3sf)
9) 303000 g (3sf)
10) 98.6 g (3sf)
11) 1210 g (3sf)
12) 1250 g (3sf)
13) 42.9 g (3sf)

TASK 10 – THE IDEAL GAS EQUATION

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

2 1.24×10^{-3} m^3 (3 sf)
3 0.786 (3 sf)
4 1.4×10^{5} m^3 (2 sf)
5 155 K (3 sf)
6 71.0 (3 sf)
7 3.80×10^{-3} m^3 (3 sf)
8 7.75×10^{-4} m^3 (3 sf)

9 3.36 g (3 sf)
10 5.33×10^{-4} m^3 (2 sf)
11 4.65 m^3 (3 sf)
12 64.1 (3 sf)
13 1.26×10^{5} Pa (3 sf)
14 342 K (3 sf)

TASK 11 – REACTING GAS VOLUMES

1 a 250 cm^3
b 150 cm^3
c 350 cm^3
2 a 650 cm^3
b 400 cm^3
c 150 cm^3

3 2.0 dm^3
4 300 cm^3
5 4 dm^3
6 20 cm^3
7 200 cm^3
8 375 cm^3
9 C_4H_8

TASK 12 – PERCENTAGE YIELD

1 a) 120 g (3 sf)
b) 75.0% (3sf)
2 a) 6.99×10^{5} g (3 sf)
b) 93.0% (3sf)
3 a) 510 g (3 sf)
b) 30.0% (3sf)

4 a) 20.2 g (3 sf)
b) 89.1% (3sf)
5 a) 529 g (3 sf)
b) 94.4% (3sf)
6 a) 330 g (3 sf)
b) 90.8% (3sf)
7 88.36% (4sf)

TASK 13 – ATOM ECONOMY

1 39.3% (3 sf)
2 14% (2 sf)
3 45.8% (3 sf)
4 56.0% (3 sf)
5 100%
6 47.1% (3 sf)

7 a) 327 g (3 sf)
b) 86.3% (3sf)
c) 29.5% (3 sf)

1) a) $Zn(NO_3)_2$ e) P_4

b) Pb f) N_2

c) Cr_2O_3 g) $Ba(OH)_2$

d) $(NH_4)_2SO_4$ h) $Al_2(SO_4)_3$

2)

Acid	Formula of acid	Base	Formula of base	Molar ratio of acid:base
sulfuric acid	H_2SO_4	potassium hydroxide	KOH	1 : 2
hydrochloric acid	HCl	potassium hydrogencarbonate	$KHCO_3$	1 : 1
nitric acid	HNO_3	ammonia	NH_3	1 : 1
hydrochloric acid	HCl	zinc carbonate	$ZnCO_3$	2 : 1

3) a) $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

b) $Ba^{2+}(aq) + 2\ OH^-(aq) \rightarrow Ba(OH)_2(s)$

c) $H^+(aq) + NH_3(aq) \rightarrow NH_4^+(aq)$

d) $H^+(aq) + HCO_3^-(aq) \rightarrow H_2O(l) + CO_2(g)$

4) a) Average mass of an atom of an element relative to $\frac{1}{12}$th the mass of ^{12}C atom

b) By definition

c) there are other C isotopes present in carbon

5) a) 3.33 mol

b) 3.33 mol

c) 20 mol

d) 0.0333 mol

6) $3.10 \times 10^{-4}\ m^3$ (3 sf)

7) 8.50×10^{-3} mol (3 sf)

8) a) volume of CO_2 formed = 57.1 cm^3

b) volume of CO_2 formed = 200 cm^3
total volume of gases at end = 350 cm^3

c) volume of CO_2 formed = 228.6 cm^3
total volume of gases at end = 314.3 cm^3

9) $2.01 \times 10^{-3}\ m^3$ (3 sf)

10) 1.65 m^3 (3 sf)

11) a) 40 mol, 60 mol

b) 40 mol, 20 mol

c) 5.84 mol, 8.76 mol

12) 19 g (2 sf)

13) 9.39 g (3 sf)

14) a) 1250 g (3 sf)

b) i) 96.0% (3sf)

c) 100%

15) a) 529 g (3 sf)

b) 94.8% (3sf)

c) 52.9% (3 sf)

16) 7 (integer)

17) a) i) 0.0500 mol (3 sf)

ii) 0.0500 mol (3 sf)

iii) $1.21 \times 10^{-3}\ m^3$

iv) 4.07 g (3 sf)

b) i) 1.30 g (3 sf)

ii) 2.77 g

TASK 14a – TITRATION CALCLATIONS 1

1 a 0.100 mol (3 sf)
b 0.250 mol (3 sf)
c 2.50×10^{-3} mol (3 sf)

2 a 0.160 mol dm^{-3} (3 sf)
b 2.50 mol dm^{-3} (3 sf)
c 0.0525 mol dm^{-3} (3 sf)

3 a 0.050 dm^3 (2 sf)
b 1.00×10^{-3} dm^3 (3 sf)

4 a 0.0538 mol dm^{-3} (3 sf)
b 9.21 g dm^{-3} (3 sf)

5 0.0188 mol dm^{-3} (3 sf)

6 0.00750 dm^3 (3 sf)

7 0.0501 mol dm^{-3} (3 sf)
7.11 g dm^{-3} (3 sf)

8 1.13 g (3 sf)

9 79.9 dm^3 (3 sf)

10 87.8 (3 sf)

11 2 (integer)

12 39.0 $\therefore$ M = potassium

TASK 14b – BACK TITRATION CALCLATIONS

1 0.15
2 1.75
3 4.2 g
4 87.7%
5 0.606 g
6 90.8%
7 4.68 g

1 $C_5H_{11}NO$
2 $C_{11}H_{14}O_2$ Molecular formula = $C_{11}H_{14}O_2$
3 526 g (3 sf)
4 2.71 g (3 sf)
5 5.00 dm^3 (3 sf)
6 0.0241 mol dm^{-3} (3 sf)
7 235 (3 sf)
8 3.21%
9 55.0%
10 1.30×10^8 g (3 sf)

1 35.1%
2 4.03 g
3 C_4H_8
4 C_8H_{18}
5 1.30 g
6 a 3.21 : 1
b 130 g
7 NS
8 C_2H_4
9 9.67%
10 A