GCE

Moles, Formulae and Equations
Edexcel Advanced GCE in Chemistry (9080)
Edexcel Advanced GCE in Chemistry (Nuffield) (9086)

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Workbook for GCE students

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Introduction

This workbook has been developed from an earlier version offering support to students in transition from GCSE Science (Double Award) and the GCE Advanced Subsidiary.

The aim of the booklet is to help students to practise their skills in the areas of formulae, equations and simple mole equations. The booklet gives examples for students to work through to help build their confidence. There are some sections involving multi-step calculations.

Edexcel acknowledges the help and support received from teachers in updating this latest edition. It replaces previous versions issued in January 1998 and August 2000.

Contents

Section 1

Atoms

All matter is made of particles. At one time, it was thought that the tiniest particle was the *atom*; the word comes from the Greek word meaning ‘indivisible’.

We now know that atoms can be split and that there are smaller particles than atoms, the so-called sub-atomic particles, electrons, protons and neutrons. You will need to know something about these particles which make up the different kinds of atoms.

However, you must understand that chemistry is all about rearrangements of atoms *that do not themselves* change.

Atoms are *very* small. The hydrogen atom, the smallest and lightest of all atoms, has a diameter of about 10^8 mm. 1 g of hydrogen atoms contains about 6 x 10^{23} atoms. It is very difficult to ‘see’ an individual atom and to find its mass.

An *atom* is the smallest, electrically neutral, particle of an element that can take part in a chemical change.

A *molecule* is the smallest, electrically neutral, particle of an element or compound that can exist on its own.

An *ion* is an atom, or group of atoms, which carries an electric charge.

You need to know these definitions by heart, but you also need to be able to recognise the formulae of atoms and molecules when you see them. Li, O, Cl, C are all formulae which represent atoms. Some of these can exist on their own, but not all of them. Oxygen, for example, always exists as oxygen *molecules*, O_2, which contain two atoms, unless it is combined with something else. Water contains only one atom of oxygen but here it is combined with two hydrogen atoms.

Make sure that you really understand these ideas:

- a single oxygen atom, O, cannot exist on its own
- a single oxygen atom can exist when it is combined with something else, but then it is part of a molecule
- an oxygen molecule has two oxygen atoms, O_2
- a few elements exist as single atoms: for these elements, an atom is the same as a molecule.

Structure of the atom

The atom is composed of electrons, neutrons and protons. You have to remember the relative mass of, and the electric charge on, each.

Particle	Relative mass (Carbon -12 scale)	Relative charge (on scale electron charge = -1 unit)
Proton	1	+1
Electron	1/1840	–1
Neutron	1	0

The atom is mostly empty space. It has a solid core or *nucleus*, the centre that contains the protons and neutrons. The electrons circulate round the nucleus in specific *orbits* or *shells*.

We can picture the hydrogen atom - the simplest of all atoms with one electron, and one proton in the nucleus - by considering a pea placed in the centre of a football pitch, to represent the nucleus with its proton. On this scale the electron will revolve in a circular orbit round the goal posts. Between the electron and the nucleus is empty space.

Atoms are the particles whose symbols are found in the periodic table given in all your examination papers and also on page 113 of this book. You can see there are only about 100 of them. The middle part of the atom, the nucleus, contains one or more protons. It is the number of protons that make the atom what it is. An atom with one proton is always a hydrogen atom; one with two protons is a helium atom and so on.

There are more substances in the world than the 100 or so different kinds of atom. The other substances are made by combining atoms in various ways to make molecules.

When a chemical reaction takes place the atoms are rearranged to make different molecules but no atoms can be made or destroyed. To show this you have to be able to find a method of counting the atoms that take part in a reaction and its products.

The mass of an individual atom is very small and it is much more convenient to measure atomic masses as *relative* masses.

The definition of *relative atomic mass* $\mathbf{A_r}$ is:

The mass of a single atom on a scale on which the mass of an atom of carbon — 12 has a mass of 12 atomic mass units. The *relative* atomic mass does not have units.

The definition of *Relative Molecular Mass* $\mathbf{M_r}$ (also referred to as ***Molar Mass***) is

The mass of a single molecule on a scale on which the mass of an atom of carbon — 12 has a mass of 12 atomic mass units.

Relative Molecular Mass of a molecule is calculated by adding together the relative atomic masses of the atoms in the chemical formulae.

Relative formula mass: in many ways this is more accurate than Relative Molecular Mass. Many salts, even in the solid state, exist as ions rather than molecules. Although the formula of sodium chloride is normally given as NaCl, it is not a simple molecule but a giant lattice and it is more accurately written as $(Na^+Cl^-)_n$. Since this compound does not have molecules, it cannot have relative 'molecular' mass. However, the principle is the same: add the relative atomic masses of sodium (23) and chlorine (35.5) to give 58.5, the relative formula mass of NaCl.

Remember: relative atomic mass, molecular mass and formula mass have no units.

Examples: Calculation of Molar Mass from Relative Atomic Mass data

Before you start any of these questions make sure you read the *Section 4* of this booklet (The mole on page 27).

When you carry out experiments you will weigh chemicals in grams. Molar mass has the same numerical value as the *Relative Molecular Mass*; it is calculated by adding together the relative atomic masses of the elements in the molecule. The total is expressed in units of grams per mol or g mol^{-1}.

Example 1

Calculate the Molar Mass of sulphuric acid H_2SO_4

This molecule contains

2 atoms of hydrogen each of mass 1	= 2 x 1	= 2 g mol^{-1}
1 atom of **sulphur** of mass 32	= 1 x 32	= 32 g mol^{-1}
4 atoms of **oxygen** of mass 16	= 4 x 16	= 64 g mol^{-1}
	Total mass	**= 98 g mol^{-1}**

Example 2

Calculate the Molar Mass of lead nitrate $Pb(NO_3)_2$

Care! This molecule contains **TWO** nitrate groups

1 atom of **lead** of mass 207	= 1 x 207	= 207 g mol^{-1}
2 atoms of **nitrogen** of mass 14	= 2 x 14	= 28 g mol^{-1}
6 atoms of **oxygen** of mass 16	= 6 x 16	= 96 g mol^{-1}
	Total mass	**= 331 g mol^{-1}**

Example 3

Calculate the Molar Mass of $CuSO_4.5H_2O$

Care! This molecule has 5 molecules of water attached to each molecule of copper sulphate. Many students make the mistake of thinking that there are 10 hydrogens and only 1 oxygen.

In $CuSO_4$	1 atom of **copper** of mass 63.5	= 1 x 63.5	= 63.5 g mol^{-1}
	1 atom of **sulphur** of mass 32	= 1 x 32	= 32 g mol^{-1}
	4 atoms of **oxygen** of mass 16	= 4 x 16	= 64 g mol^{-1}
In $5H_2O$	5 x 2 atoms of **hydrogen** of mass 1	= 10 x 1	= 10 g mol^{-1}
	5 x 1 atoms of **oxygen** of mass 16	= 5 x 16	= 80 g mol^{-1}
		Total mass	**= 249.5 g mol^{-1}**

Calculations of this type are generally written as follows

$CuSO_4.5H_2O$ = [63.5 + 32 + (4 x 16) + 5{(2x1) + 16}] = 249.5 g mol^{-1}

Exercise 1

Calculation of the Molar Mass of compounds

Calculate the Molar Mass of the following. You will find data concerning Relative Atomic Masses on the periodic table (on page 113). When you have finished this set of calculations keep the answers for reference. You will find them useful in some of the other questions in this workbook.

1	H_2O
2	CO_2
3	NH_3
4	C_2H_5OH
5	C_2H_4
6	SO_2
7	SO_3
8	HBr
9	H_2SO_4
10	HNO_3
11	NaCl
12	$NaNO_3$
13	Na_2CO_3
14	NaOH
15	Na_2SO_4
16	$KMnO_4$
17	K_2CrO_4
18	$KHCO_3$
19	KI
20	$CsNO_3$
21	$CaCl_2$

22	$Ca(NO_3)_2$
23	$Ca(OH)_2$
24	$CaSO_4$
25	$BaCl_2$
26	$AlCl_3$
27	$Al(NO_3)_3$
28	$Al_2(SO_4)_3$
29	$FeSO_4$
30	$FeCl_2$
31	$FeCl_3$
32	$Fe_2(SO_4)_3$
33	PbO
34	PbO_2
35	Pb_3O_4
36	$Pb(NO_3)_2$
37	$PbCl_2$
38	$PbSO_4$
39	$CuCl$
40	$CuCl_2$
41	$CuSO_4$
42	$ZnCl_2$
43	$AgNO_3$
44	NH_4Cl
45	$(NH_4)_2SO_4$
46	NH_4VO_3
47	$KClO_3$
48	KIO_3

49	NaClO
50	$NaNO_2$
51	$CuSO_4.5H_2O$
52	$FeSO_4.7H_2O$
53	$(NH_4)_2SO_4.Fe_2(SO_4)_3.24H_2O$
54	$Na_2S_2O_3.5H_2O$
55	$(COOH)_2.2H_2O$
56	$MgSO_4.7H_2O$
57	$Cu(NH_3)_4SO_4.2H_2O$
58	CH_3CO_2H
59	CH_3COCH_3
60	$C_6H_5CO_2H$

Section 2

Chemical formulae

A chemical formula is a useful shorthand method for describing the atoms in a chemical: sometimes you will see the formula used instead of the name, but you should **not** do this if you are asked for a name.

The chemical formula of an element or compound tells you:

- Which elements it contains: eg $FeSO_4$ contains iron, sulphur and oxygen
- How many atoms of each kind are in each molecule: eg H_2SO_4 contains two atoms of hydrogen, one atom of sulphur and four atoms of oxygen in each molecule
- How the atoms are arranged: eg C_2H_5OH contains a group of atoms known as the ethyl group, $-C_2H_5$, and a hydroxyl group, -OH
- The masses of the various elements in a compound: eg 18 g of water, H_2O, contains 2 g of hydrogen atoms and 16 g of oxygen since the relative atomic mass of hydrogen is 1 (x 2 because there two hydrogen atoms) and that of oxygen is 16.

You should not learn large numbers of chemical formulae by heart. However, it is useful to know a few of them and when you do you should be able to work out the rest. The table on page 10 shows the names, formulae and valency of the more common elements and some groups of atoms, called radicals, that you will study and you should refer to it when necessary.

Although it's best to learn formulae by using the valency of the common parts, it is sometimes useful to be able to work out the formula of a compound. This set of rules helps you to do this using information in the table.

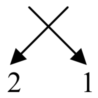
You can think of valency as the combining power and use it to show the simplest ratio in which the atoms of the elements and radicals combine together in the formula. The following rules can now be applied:

- Write down the symbols of the elements and radicals given in the chemical name of the compound
- Now write down the valency of each element or radical under the corresponding symbols for the element or radical
- Now cross them over as shown in the example on page 10
- The valency shows the *simplest* combining ratio and may be cancelled down but only the valency can be simplified in this way
- If an element has more than one valency, the name of the compound will indicate which valency is to be used.

Here are a few examples:

- Sodium Sulphate

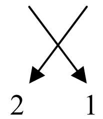
$NaSO_4$



= Na_2SO_4

- Calcium hydrogen carbonate

$Ca(HCO_3)$



= $Ca(HCO_3)_2$

Note: A bracket *must* be placed around the radical if it is multiplied by 2 or more *and* composed of more than one element.

Eg $MgBr_2$ no bracket required
$Ca(OH)_2$ bracket *essential* as $CaOH_2$ is incorrect.

- Often you can cancel the numbers on the two formulae:

  $Ca_2(CO_3)_2 = CaCO_3$

  However, you should **not** do this for organic compounds: C_2H_4 has two atoms

  of carbon and four of hydrogen so it cannot be cancelled down to CH_2.

- Copper(I) oxide means use copper valency 1, ie Cu_2O: lead(II) nitrate means use lead valency 2, ie $Pb(NO_3)_2$

The periodic table can help you to find the valency of an element and hence the formula of its compounds.

Although you can use the table above to work out the formulae of many compounds it is important to realise that all formulae were originally found by experiment.

On page 11 you will find a table of the more common elements and groups that you may have met at GCSE. Also included are a few that you will meet in the first few weeks of your Advanced course or are mentioned in some of the calculations in this booklet. These are in italics.

Symbols and Valences of Common Elements and Radicals

ELEMENTS			RADICALS		
	Symbol	**Valency**		**Symbol**	**Valency**
Aluminium	Al	3	Ammonium	NH_4	1
Barium	Ba	2	Carbonate	CO_3	2
Bromine	Br	1	Chloride	Cl	1
Calcium	Ca	2	Hydrogen-carbonate	HCO_3	1
Carbon	C	4	Hydrogen-sulphate	HSO_3	1
Chlorine	Cl	1	Hydroxide	OH	1
Cobalt	Co	2	Nitrate	NO_3	1
Copper	Cu	1&2	Nitrite	NO_2	1
Hydrogen	H	1	Sulphate	SO_4	2
Iodine	I	1	Sulphite	SO_3	2
Iron	Fe	2&3			
Lead	Pb	2&4	*Chlorate(I)*	*ClO*	*1*
Magnesium	Mg	2	*Chlorate(V)*	ClO_3	*1*
Manganese	Mn	2&4	*Vanadate(V)*	VO_3	*1*
Mercury	Hg	1&2	*Manganate(VII)*	MnO_4	*1*
Nitrogen	N	3&5	*Chromate(VI)*	CrO_4	*2*
Oxygen	O	2	*Dichromate(VI)*	Cr_2O_7	*2*
Phosphorus	P	3&5			
Potassium	K	1			
Silicon	Si	4			
Silver	Ag	1			
Sodium	Na	1			
Sulphur	S	2,4,6			

Exercise 2

Writing formulae from names

Use the data in the table on page 11 to write the formulae of the following. Before you start this exercise, make sure you have read *Section 3* (*Naming of compounds* on page 19) of this booklet.

1	Sodium Chloride
2	Sodium Hydroxide
3	Sodium Carbonate
4	Sodium Sulphate
5	Sodium Phosphate
6	Potassium Chloride
7	Potassium Bromide
8	Potassium Iodide
9	Potassium Hydrogen Carbonate
10	Potassium Nitrite
11	Magnesium Chloride
12	Magnesium Nitrate
13	Magnesium Hydroxide
14	Magnesium Oxide
15	Magnesium Carbonate

16	Calcium Oxide
17	Calcium Chloride
18	Calcium Sulphate
19	Calcium Carbonate
20	Barium Chloride
21	Barium Sulphate
22	Aluminium Chloride
23	Aluminium Oxide
24	Aluminium Hydroxide
25	Aluminium Sulphate
26	Copper(II) Sulphate
27	Copper(II) Oxide
28	Copper(II) Chloride
29	Copper(II) Nitrate
30	Copper(I) Oxide
31	Copper(I) Chloride
32	Zinc Nitrate
33	Zinc Carbonate

34	Zinc Oxide
35	Silver Chloride
36	Silver Bromide
37	Silver Iodide
38	Silver Nitrate
39	Silver Oxide
40	Lead(II) Nitrate
41	Lead(II) Carbonate
42	Lead(II) Oxide
43	Lead(IV) Oxide
44	Lead(II) Chloride
45	Lead(IV) Chloride
46	Lead(II) Sulphide
47	Tin(II) Chloride
48	Tin(IV) Chloride
49	Iron(II) Sulphate
50	Iron(II) Chloride
51	Iron(III) Sulphate
52	Iron(III) Chloride

53	Iron(III) Hydroxide	
54	Iron(II) Hydroxide	
55	Ammonium Chloride	
56	Ammonium Carbonate	
57	Ammonium Hydroxide	
58	Ammonium Nitrate	
59	Ammonium Sulphate	
60	Ammonium Phosphate	
61	Phosphorus Trichloride	
62	Phosphorus Pentachloride	
63	Phosphorus Trioxide	
64	Phosphorus Pentoxide	
65	Hydrogen Phosphate (Phosphoric Acid)	
66	Hydrogen Sulphate (Sulphuric Acid)	
67	Hydrogen Nitrate (Nitric Acid)	
68	Hydrogen Chloride (Hydrochloric Acid)	
69	Carbon Tetrachloride	
70	Silicon Tetrachloride	

71	Silicon Dioxide
72	Sulphur Dioxide
73	Sulphur Trioxide
74	Hydrogen Sulphide
75	Chlorine(I) Oxide
76	Nitrogen Dioxide
77	Nitrogen Monoxide
78	Carbon Dioxide
79	Carbon Monoxide
80	Hydrogen Hydroxide

Section 3

Naming of compounds

At Advanced Level you will meet many compounds that are new to you; a lot of these will be organic compounds. In this section, we will be looking at the naming of compounds that you may already have met at GCSE level. Many of these compounds are named using simple rules. However, there are some that have 'trivial' names not fixed by the rules. It is important that you learn the names and formulae of these compounds. Later in the course, you will learn the rules for naming most of the organic compounds you will meet.

Naming inorganic compounds

The name must show which elements are present and, where confusion is possible, the valency of the elements concerned.

1 You need to remember that if there are only two elements present then the name will end in **-ide**

Thus, **oxides** contain an element and oxygen

eg	Na_2O	is	**Sodium Ox<u>ide</u>**
	CaO	is	**Calcium Ox<u>ide</u>**

Chlorides contain an element and chlorine

eg	$MgCl_2$	is	**Magnesium Chlor<u>ide</u>**
	$AlCl_3$	is	**Aluminium Chlor<u>ide</u>**

Bromides and **Iodides** have an element and either bromine or iodine

eg	KBr	is	**Potassium Brom<u>ide</u>**
	ZnI	is	**Zinc Iod<u>ide</u>**

Hydrides contain an element and hydrogen and **Nitrides** an element and nitrogen.

eg	LiH	is	**Lithium Hydr<u>ide</u>**
	Mg_3N_2	is	**Magnesium Nitr<u>ide</u>**

Other elements also form these types of compounds and the name always ends in **-ide**. The exceptions to this are **hydroxides** that have the -OH group and **cyanides**, which have the **-CN** group.

eg	NaOH	is	**Sodium Hydroxide**
	$Ca(OH)_2$	is	**Calcium Hydroxide**
	KCN	is	**Potassium Cyanide**

2 If the elements concerned have more than one valency this may need to be shown. Thus as iron has valency **2** and **3,** the name **Iron Chloride** would not tell you which of the two possible compounds **$FeCl_2$** or **$FeCl_3$** is being considered. In this case the valency of the iron is indicated by the use of a Roman II or III in brackets after the name of the metal. In this case **Iron(II) Chloride** for **$FeCl_2$** or **Iron(III) Chloride** for **$FeCl_3$**.

eg	$PbCl_2$	is	**Lead(II) Chloride**
	$PbCl_4$	is	**Lead(IV) Chloride**
	$Fe(OH)_2$	is	**Iron(II) Hydroxide**
	$Mn(OH)_2$	is	**Manganese(II) Hydroxide**

3 For compounds containing two **non-metal** atoms the actual number of atoms of the element present are stated.

eg	CO	is	**Carbon <u>Monoxide</u>** where mon- means one
	CO_2	is	**Carbon <u>Dioxide</u>** where di- means two
	SO_2	is	**Sulphur Dioxide.** This could be called **Sulphur(IV) Oxide**
	SO_3	is	**Sulphur Trioxide**. This could be called **Sulphur(VI) Oxide**
	PCl_3	is	**Phosphorus Trichloride**.
			This could be called **Phosphorus(III) Chloride**
	PCl_5	is	**Phosphorus Pentachloride**.
			This could be called **Phosphorus(V) Chloride**
	CCl_4	is	**Carbon Tetrachloride** and
	$SiCl_4$	is	**Silicon Tetrachloride.**

4 Where a compound contains a **metal,** a **non-metal** and **oxygen** it has a name ending in **-ate** or **-ite**. You need to remember the names and formulae of the groups listed on page 11. To cover the ideas we will look at the following groups

Carbonate	**$-CO_3$**
Sulphate	**$-SO_4$**
Nitrate	**$-NO_3$**

Thus a compound of sodium, carbon and oxygen would be Na_2CO_3 and would be called **Sodium Carbon<u>ate.</u>**

eg	$NaNO_3$	is	**Sodium Nitrate**
	$Mg(NO_3)_2$	is	**Magnesium Nitrate**
	$Fe_2(SO_4)_3$	is	**Iron(III) Sulphate**
	$FeSO_4$	is	**Iron(II) Sulphate**

5 Because most non-metals can have more than one valency they can also produce more than one acid upon which these groups are based. Thus sulphur can form **sulphates** and **sulphites.** The ending **-ite** is used when an element forms more than one such compound. In all cases the **-ite** is used for the compound with the lower number of oxygens atoms. **Sulphate** can also be referred to as **sulphate(VI)** and **sulphite** can also be referred to as **sulphate(IV).** In the case of nitrogen with oxygen the compounds would be **nitrate** and **nitrite** or **nitrate(V)** and **nitrate(III).**

In summary:

Common name	*Systematic name*	*Formulae*
Sulphate	**Sulphate(VI)**	**$-SO_4$**
Sulphite	**Sulphate(IV)**	**$-SO_3$**
Nitrate	**Nitrate(V)**	**$-NO_3$**
Nitrite	**Nitrate(III)**	**$-NO_2$**
Chlorate	**Chlorate(V)**	**$-ClO_3$**
Hypochlorite	**Chlorate(I)**	**-ClO**

Great care needs to be taken when using these systematic names, as they are called, because the properties of the two groups of compounds will be very different. In some cases the use of the wrong compound in a reaction could cause considerable danger. For this reason you should always read the label on a bottle or jar and make sure it corresponds exactly to what you should be using.

Other elements can form compounds involving oxygen in this way. These include **Chlorate(V), Chromate(VI), Manganate(VII)** and **Phosphate(V).**

eg	KNO_2	is	**Potassium Nitrite** or **Potassium Nitrate(III)**
	Na_2SO_3	is	**Sodium Sulphite** or **Sodium Sulphate(IV)**
	K_2CrO_4	is	**Potassium Chromate(VI)**
	$KMnO_4$	is	**Potassium Manganate(VII)**
	$KClO_3$	is	**Potassium Chlorate(V)**

6 When a compound is considered it is usual to put the metal down first both in the name and the formula. The exceptions to this rule are in organic compounds where the name has the metal first but the formula has the metal at the end.

eg CH_3COONa is **Sodium Ethanoate**

7 The elements nitrogen and **hydrogen** can join together to form a group called the **ammonium** group. This must not be confused with the compound **ammonia**, but more of that later. This **ammonium** group has the formula $\mathbf{NH_4^+}$ and sits in the place generally taken by a metal in the formula.

eg	NH_4Cl	is	**Ammonium Chloride**
	$(NH_4)_2SO_4$	is	**Ammonium Sulphate**
	NH_4ClO_3	is	**Ammonium Chlorate(V)**

8 There are a small number of simple molecules that do not follow the above rules. You will need to learn their names and formulae**.**

They include:

Water	which is H_2O
Sulphuric Acid	which is H_2SO_4
Nitric Acid	which is HNO_3
Hydrochloric Acid	which is HCl
Ammonia	which is NH_3
Methane	which is CH_4

8 Organic compounds have their own set of rules for naming but you will need to learn some of the basic rules. The names are generally based on the names of the simple hydrocarbons. These follow a simple pattern after the first four:

CH_4	is	**Methane**
C_2H_6	is	**Ethane**
C_3H_8	is	**Propane**
C_4H_{10}	is	**Butane**

After butane the names are based on the prefix for the number of carbons C_5-**pent**, C_6 **- hex** and so on.

Thus organic compounds with 2 carbons will either start with **Eth-** or have **-eth-** in their name.

eg	C_2H_4	is	**<u>Eth</u>ene**
	C_2H_5OH	is	**<u>Eth</u>anol**
	CH_3COOH	is	**<u>Eth</u>anoic Acid**
	C_2H_5Cl	is	**Chloro<u>eth</u>ane**

Exercise 3

Names from formulae

Use the notes in this section, the data in the table on page 11 and the copy of the periodic table on page 113 to write the names of the following. Before you start this exercise make sure you have read *Section 2* of this booklet (*Chemical formulae* on page 9).

1	H_2O
2	CO_2
3	NH_3
4	O_2
5	H_2
6	SO_2
7	SO_3
8	HCl
9	HI
10	HF
11	CH_4
12	H_2S
13	HBr
14	H_2SO_4
15	HNO_3
16	$NaCl$
17	$NaNO_3$
18	Na_2CO_3
19	$NaOH$
20	Na_2SO_4
21	$CaCl_2$
22	$Ca(NO_3)_2$
23	$Ca(OH)_2$

24	$CaSO_4$
25	$BaCl_2$
26	$AlCl_3$
27	$Al(NO_3)_3$
28	$Al_2(SO_4)_3$
29	$FeSO_4$
30	$FeCl_2$
31	$FeCl_3$
32	$Fe_2(SO_4)_3$
33	PbO
34	PbO_2
35	$Pb(NO_3)_2$
36	$PbCl_2$
37	$PbSO_4$
38	$Cu(NO_3)_2$
39	CuCl
40	$CuCl_2$
41	$CuSO_4$
42	$ZnCl_2$
43	$AgNO_3$
44	NH_4Cl
45	$(NH_4)_2SO_4$
46	NH_4VO_3 (V is Vanadium)
47	$KClO_3$
48	KIO_3
49	NaClO
50	$NaNO_2$

51	C_2H_6
52	C_4H_{10}
53	C_8H_{18}
54	$(NH_4)_2CO_3$
55	$KMnO_4$
56	K_2CrO_4
57	$KHCO_3$
58	KI
59	$Co(NO_3)_2$
60	KAt

Section 4

The mole

When chemists measure how much of a particular chemical reacts they measure the amount in grams; or they measure the volume of a gas. However, chemists find it convenient to use a unit called a ***mole***. You need to know several definitions of a mole and be able to use them.

- The **mole** is the amount of substance, which contains the same number of particles (atoms, ions, molecules, formulae or electrons) as there are carbon atoms in 12 g of carbon -12
- This **number** is known as the *Avogadro constant, L,* and is equal to 6.02 x 10^{23} mol^{-1}
- The **molar mass** of a substance is the mass, in grams, of one mole
- The **molar volume** of a gas is the volume occupied by one mole at room temperature and atmospheric pressure (r.t.p). It is equal to 24 dm^3 at r.t.p
- *Avogadro's Law* states that equal volumes of all gases, under the same conditions of temperature and pressure contain the same number of moles or molecules. If the volume is 24 dm^3, at room temperature and pressure, this number, once again, is the Avogadro constant.

When you talk about moles, you must always state whether you are dealing with atoms, molecules, ions, formulae etc. To avoid any ambiguity it is best to show this as a formula.

Example calculations involving the use of moles

These calculations form the basis of many of the calculations you will meet at A level.

Example 1

Calculation of the number of moles of material in a given mass of that material

a Calculate the number of moles of oxygen atoms in 64 g of oxygen atoms. *You need the mass of one mole of oxygen atoms. This is the Relative Atomic Mass in grams; in this case it is 16 g mol^{-1}.*

$$\textbf{number of moles of atoms} = \frac{\textbf{mass in grams}}{\textbf{molar mass of atoms}}$$

$$\therefore \text{ number of moles of oxygen} = \frac{\text{64 g of oxygen atoms}}{\text{molar mass of oxygen of 16 g mol}^{-1}}$$

= **4 moles of oxygen atoms**

b Calculate the number of moles of chlorine molecules in 142 g of chlorine gas.

$$\textbf{number of moles of atoms} = \frac{\textbf{mass in grams}}{\textbf{molar mass of atoms}}$$

The first stage of this calculation is to calculate the molar mass of Chlorine molecules.
Molar mass of Cl_2 = 2 x 35.5 = 71 g mol^{-1}

$$\therefore \text{ number of moles of chlorine} = \frac{\text{142 g of chlorine gas}}{\text{molar mass of chlorine of 71 g mol}^{-1}}$$

= **2 moles of chlorine molecules**

c Calculate the number of moles of $CuSO_4.5H_2O$ in 100 g of the solid.

The Relative Molecular Mass of $CuSO_4.5H_2O$ =

[63.5 + 32 + (4 x 16) + 5{(2x1) + 16}] = 249.5 g mol^{-1}

$$\therefore \text{ number of moles of } CuSO_4.5H_2O = \frac{100\text{ g of } CuSO_4.5H_2O}{\text{molecular mass of } CuSO_4.5H_2O \text{ of } 249.5\text{ g mol}^{-1}}$$

= **0.4008 moles of $CuSO_4.5H_2O$ molecules**

Example 2

Calculation of the mass of material in a given number of moles of that material

The mass of a given number of moles	**=**	**the mass of 1 mole**	**x**	**the number of moles of material concerned**

a Calculate the mass of 3 moles of sulphur dioxide SO_2

1 mole of sulphur dioxide has a mass = 32 + (2x16) = 64 g mol^{-1}

$\therefore$ 3 moles of SO_2 = 3 x 64 **= 192 g**

b What is the mass of 0.05 moles of $Na_2S_2O_3.5H_2O$?

1 mole of $Na_2S_2O_3.5H_2O$ = [(23 x 2) + (32 x 2) + (16 x 3)] + 5[(2 x 1) +16]
= 248 g mol^{-1}

$\therefore$ 0.05 moles of $Na_2S_2O_3.5H_2O$ = 0.05 x 248 **= 12.4 g**

Example 3

Calculation of the volume of a given number of moles of a gas

All you need to remember is that **1 mole of any gas has a volume of 24 dm^3 (24000 cm^3) at room temperature and pressure**.

∴	**The volume of a given number of moles of gas**	=	**number of moles**	x	**24000 cm^3**

a What is the volume of 2 mol of carbon dioxide?

Remember you do not need to work out the molar mass to do this calculation as it does not matter what gas it is.

∴ 2 moles of carbon dioxide = 2 x 24000 cm^3 = 48000 cm^3 **= 48 dm^3**

b What is the volume of 0.0056 moles of chlorine molecules?

Volume of 0.0056 moles of chlorine = 0.0056 x 24000 cm^3 **= 134.4 cm^3**

Example 4

Calculation of the number of moles of gas in a given volume of that gas

$$\textbf{number of moles of gas} = \frac{\textbf{volume of gas in cm}^3}{\textbf{24 000 cm}^3}$$

a Calculate the number of moles of hydrogen molecules in 240 cm^3 of the gas.

$$\text{number of moles} = \frac{240\,\text{cm}^3}{24\ 000\,\text{cm}^3} = 0.010\,\text{moles}$$

b How many moles of a gas are there in 1000 cm^3 of the gas?

$$\text{number of moles of gas} = \frac{1000\,\text{cm}^3}{24\,000\,\text{cm}^3} = 0.0147\,\text{moles}$$

Example 5

Calculation of the volume of a given mass of gas

This calculation require you to apply the skills covered in the previous examples

Calculate the volume of 10 g of hydrogen gas.

This is a two-stage calculation a) you need to calculate how many moles of hydrogen gas are present, and b) you need to convert this to a volume.

$$\therefore \text{ number of moles of hydrogen } (H_2) = \frac{10 \text{ g of hydrogen } (H_2)}{\text{molecular mass of hydrogen } (H_2) \text{ of } 2 \text{ g mol}^{-1}}$$

$$= \quad 5 \text{ moles}$$

$\therefore$ 5 moles of hydrogen = 5 x 24000 cm^3 = 120000 cm^3 **= 120 dm^3**

Example 6

Calculation of the mass of a given volume of gas

This calculation require you to apply the skills covered in the previous examples

Calculate the mass of 1000 cm^3 of carbon dioxide

Again this is a two-stage calculation a) you need to calculate the number of moles of carbon dioxide and then b) convert this to a mass.

$$\therefore \text{ number of moles of } CO_2 = \frac{1000 \text{ cm}^3 \text{ of } CO_2}{\text{volume of 1 mole of } CO_2 \text{ of } 24\,000 \text{ cm}^3}$$

$$= \quad 0.0147 \text{ moles}$$

$\therefore$ 0.0147 moles of carbon dioxide = 0.0147 x 44 g **= 1.833 g**

Example 7

Calculation of the molar mass of a gas from mass and volume data for the gas

Calculations of this type require you to find the mass of 1 mole of the gas, ie 24 000 cm^3. This is the molar mass of the gas.

eg Calculate the Relative Molecular Mass of a gas for which 100 cm^3 of the gas at room temperature and pressure, have a mass of 0.0667 g

100 cm^3 of the gas has a mass of 0.0667 g

$$\therefore\ 24\,000\,\text{cm}^3 \text{ of the gas must have a mass of } = \frac{0.0667\,\text{g} \times 24\,000\,\text{cm}^3}{100\,\text{cm}^3}$$

$$= 16\ \text{g}$$

$\therefore$ **The molar mass of the gas is 16 g mol^{-1}**

Exercise 4a

Calculation of the number of moles of material in a given mass of that material

In this set of calculations all the examples chosen are from the list of compounds whose molar mass you calculated in exercise 1.

In each case calculate the number of moles of the material in the mass stated.

1	9.00 g of H_2O
2	88.0 g of CO_2
3	1.70 g of NH_3
4	230 g of C_2H_5OH
5	560 g of C_2H_4
6	0.640 g of SO_2
7	80.0 g of SO_3
8	18.0 g of HBr
9	0.0960 g of H_2SO_4
10	3.15 g of HNO_3
11	19.3 g of NaCl
12	21.25 g of $NaNO_3$
13	2.25 g of Na_2CO_3
14	0.800 g of NaOH
15	17.75 g of Na_2SO_4

16	3.16 g of $KMnO_4$
17	32.33 g of K_2CrO_4
18	100 g of $KHCO_3$
19	7.63 g of KI
20	3.90 g of $CsNO_3$
21	0.111 g of $CaCl_2$
22	41.0 g of $Ca(NO_3)_2$
23	1.48 g of $Ca(OH)_2$
24	3.40 g of $CaSO_4$
25	41.6 g of $BaCl_2$
26	14.95 g of $CuSO_4$
27	13.64 g of $ZnCl_2$
28	1.435 g of $AgNO_3$
29	13.76 g of NH_4Cl
30	13.76 g of $(NH_4)_2SO_4$
31	23.4 g of NH_4VO_3
32	10.0 g of $KClO_3$
33	10.7 g of KIO_3
34	100 g of NaClO

35	1.70 g of $NaNO_2$
36	50.9 g of $CuSO_4.5H_2O$
37	19.6 g of $FeSO_4.7H_2O$
38	9.64 g of $(NH_4)_2SO_4.Fe_2(SO_4)_3.24H_2O$
39	12.4 g of $Na_2S_2O_3.5H_2O$
40	32.0 g of $(COOH)_2.2H_2O$
41	3.075 g of $MgSO_4.7H_2O$
42	40.0 g of $Cu(NH_3)_4SO_4.2H_2O$
43	6.00 g of CH_3CO_2H
44	3.10 g of CH_3COCH_3
45	0.530 g of $C_6H_5CO_2H$
46	4.79 g of $AlCl_3$
47	56.75 g of $Al(NO_3)_3$
48	8.35 g of $Al_2(SO_4)_3$
49	3.8 g of $FeSO_4$
50	200 g of $FeCl_2$

Exercise 4b

Calculation of the mass of material in a given number of moles of the material

In each case calculate the mass in grams of the material in the number of moles stated.

1	2 moles of H_2O
2	3 moles of CO_2
3	2.8 moles of NH_3
4	0.50 moles of C_2H_5OH
5	1.2 moles of C_2H_4
6	0.64 moles of SO_2
7	3 moles of SO_3
8	1 mole of HBr
9	0.012 moles of H_2SO_4
10	0.15 moles of HNO_3
11	0.45 moles of NaCl
12	0.70 moles of $NaNO_3$
13	0.11 moles of Na_2CO_3
14	2.0 moles of NaOH
15	0.90 moles of Na_2SO_4
16	0.050 moles of $KMnO_4$

17	0.18 moles of K_2CrO_4
18	0.90 moles of $KHCO_3$
19	1.5 moles moles of KI
20	0.12 moles of $CsNO_3$
21	0.11 moles of $CaCl_2$
22	4.1 moles of $Ca(NO_3)_2$
23	0.0040 moles of $Ca(OH)_2$
24	0.10 moles of $CaSO_4$
25	0.21 moles of $BaCl_2$
26	0.10 moles of $CuSO_4$
27	0.56 moles of $ZnCl_2$
28	0.059 moles of $AgNO_3$
29	0.333 moles of NH_4Cl
30	1.1 moles of $(NH_4)_2SO_4$
31	0.025 moles of NH_4VO_3
32	0.10 moles of $KClO_3$
33	0.10 moles of KIO_3
34	10 moles of NaClO
35	0.0010 moles of $NaNO_2$

36	0.20 moles of $CuSO_4.5H_2O$
37	0.10 moles of $FeSO_4.7H_2O$
38	0.0050 moles of $(NH_4)_2SO_4.Fe_2(SO_4)_3.24H_2O$
39	0.040 moles of $Na_2S_2O_3.5H_2O$
40	2.4 moles of $(COOH)_2.2H_2O$
41	3.075 moles of $MgSO_4.7H_2O$
42	0.15 moles of $Cu(NH_3)_4SO_4.2H_2O$
43	0.17 moles of CH_3CO_2H
44	0.20 moles of CH_3COCH_3
45	0.080 moles of $C_6H_5CO_2H$
46	0.0333 moles of $AlCl_3$
47	0.045 moles of $Al(NO_3)_3$
48	0.12 moles of $Al_2(SO_4)_3$
49	2.0 moles of $FeSO_4$
50	11 moles of $FeCl_2$

Exercise 4c

Calculation of the volume of a given number of moles of a gas

In each case calculate the volume of the number of moles of gas stated.

(Assume that all volumes are measured at room temperature and pressure and that 1 mole of gas has a volume of 24 000 cm^3 under these conditions).

1	1 mole of CO_2
2	0.1 moles of NH_3
3	0.5 moles of C_2H_4
4	2 moles of SO_2
5	0.12 moles of SO_3
6	3.4 moles of HBr
7	0.11 moles of Cl_2
8	0.0040 moles of CH_4
9	10 moles of H_2
10	0.45 moles of O_2
11	0.0056 moles of C_2H_6
12	0.0090 moles of C_3H_8
13	0.040 moles of C_2H_2
14	0.123 moles of NO
15	0.0023 moles of HCl

16	8.0 moles of HBr
17	0.000010 moles of HI
18	6.0 moles of NO_2
19	0.0076 moles of F_2
20	3.0 moles of N_2

Exercise 4d

Calculation of the number of moles of gas in a given volume of that gas

In each case calculate the volume of the number of moles of gas stated.

(Assume that all volumes are measured at room temperature and pressure and that 1 mol of gas has a volume of 24 000 cm^3 under these conditions).

1	200 cm^3 of CO_2
2	500 cm^3 of NH_3
3	1000 cm^3 of C_2H_4
4	2000 cm^3 of SO_2
5	234 cm^3 of SO_3
6	226 cm^3 of HBr
7	256 cm^3 of Cl_2
8	200 cm^3 of CH_4
9	2000 cm^3 of H_2
10	2400 cm^3 of O_2
11	700 cm^3 of C_2H_6
12	5600 cm^3 of C_3H_8
13	2200 cm^3 of C_2H_2
14	210 cm^3 of NO
15	800 cm^3 of HCl

16	80 cm^3 of HBr
17	2 cm^3 of HI
18	20 000 cm^3 of NO_2
19	420 cm^3 of F_2
20	900 cm^3 of N_2

Exercise 4e

Calculation of the mass of a given volume of gas

Calculate the mass of the volume of gases stated below.
(Assume that all volumes are measured at room temperature and pressure and that 1 mol of gas has a volume of 24 000 cm^3 under these conditions).

1	200 cm^3 of CO_2
2	500 cm^3 of NH_3
3	1000 cm^3 of C_2H_4
4	2000 cm^3 of SO_2
5	234 cm^3 of SO_3
6	226 cm^3 of HBr
7	256 cm^3 of Cl_2
8	200 cm^3 of CH_4
9	2000 cm^3 of H_2
10	2400 cm^3 of O_2
11	700 cm^3 of C_2H_6
12	5600 cm^3 of C_3H_8
13	2200 cm^3 of C_2H_2
14	210 cm^3 of NO
15	800 cm^3 of HCl

16	80 cm^3 of HBr
17	2 cm^3 of HI
18	20 000 cm^3 of NO_2
19	420 cm^3 of F_2
20	900 cm^3 of N_2

Exercise 4f

Calculation of the volume of a given mass of gas

In each case calculate the volume on cm^3 of the mass of gas given.
(Assume that all volumes are measured at room temperature and pressure and that 1 mol of gas has a volume of 24 000 cm^3 under these conditions).

1	2 g of CO_2
2	5 g of NH_3
3	10 g of C_2H_4
4	20 g of SO_2
5	2.34 g of SO_3
6	2.26 g of HBr
7	10 g of Cl_2
8	20 g of CH_4
9	200 g of H_2
10	240 g of O_2
11	70 g of C_2H_6
12	56 g of C_3H_8
13	22 g of C_2H_2
14	20 g of NO
15	8 g of HCl

16	8 g of HBr
17	2 g of HI
18	23 g of NO_2
19	42 g of F_2
20	90 g of N_2

Exercise 4g

Calculation of the Relative Molecular Mass of a gas from mass and volume data for the gas

In each case you are given the mass of a certain volume of an unknown gas. From each set of data calculate the Relative Molecular Mass of the gas.

(Assume that all volumes are measured at room temperature and pressure and that

1 mol of gas has a volume of 24 000 cm^3 under these conditions).

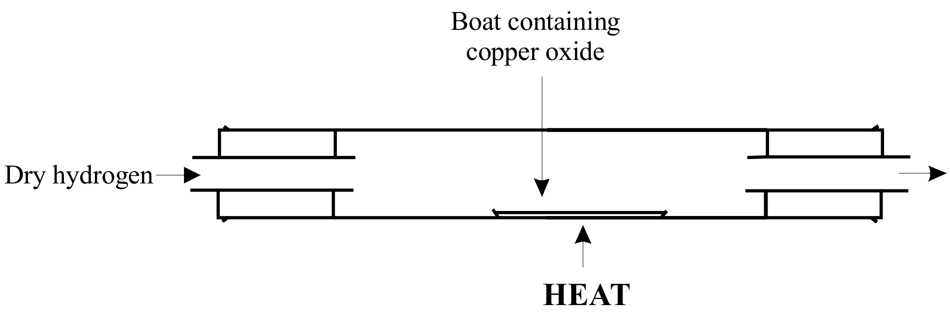
1	0.373 g of gas occupy 56 cm^3
2	0.747 g of gas occupy 280 cm^3
3	0.467 g of gas occupy 140 cm^3
4	0.296 g of gas occupy 100 cm^3
5	0.0833 g of gas occupy 1000 cm^3
6	0.175 g of gas occupy 150 cm^3
7	0.375 g of gas occupy 300 cm^3
8	0.218 g of gas occupy 90 cm^3
9	0.267 g of gas occupy 200 cm^3
10	1.63 g of gas occupy 1400 cm^3
11	0.397 g of gas occupy 280 cm^3
12	0.198 g of gas occupy 280 cm^3
13	0.0602 g of gas occupy 38 cm^3
14	0.0513 g of gas occupy 44 cm^3

15	0.0513 g of gas occupy 28 cm^3
16	1.33 g of gas occupy 1000 cm^3
17	8.79 g of gas occupy 1000 cm^3
18	0.0760 g of gas occupy 50 cm^3
19	0.338 g of gas occupy 100 cm^3
20	0.667 g of gas occupy 125 cm^3

Section 5

Using the idea of moles to find formulae

You can find the formula of copper(II) oxide by passing a stream of hydrogen over a known mass of copper oxide and weighing the copper formed.



- A known mass of copper(II) oxide is used.
- A stream of hydrogen from a cylinder is passed over the copper until all the air has been swept out of the apparatus.
- It is heated to constant mass (until two consecutive mass determinations at the end of the experiment are same) in a stream of *dry* hydrogen.
- The mass of the copper is finally determined.

Note:

- Excess hydrogen must **not** be ignited until it has been tested (by collection in a test tube) to make sure that all the air has been expelled from the apparatus. If the hydrogen in the test tube burns quietly, without a squeaky pop, then it is safe to ignite it at the end of the tube.
- The combustion tube is tilted to prevent the condensed steam from running back on to the hot part of the tube.
- When the reduction process is complete, ie after heating to constant mass, the tube is allowed to cool with hydrogen still being passed over the remaining copper. This is to prevent the copper from being oxidized to copper(II) oxide.

The working on the next page shows you how to calculate the results:

Typical results

Mass of copper (II) oxide	= 5 g
Mass of copper	= 4 g
Mass of oxygen	= 1 g

	÷ by relative atomic mass (r.a.m)	÷ by smallest	Ratio of atoms
Moles of copper atoms	$\frac{4}{64} = 0.0625$	$\frac{0.0625}{0.0625} = 1$	1
Moles of oxygen atoms	$\frac{1}{16} = 0.0625$	$\frac{0.0625}{0.0625} = 1$	1

Therefore, the simplest (or empirical) formula is CuO.

The apparatus may be modified to determine the formula of water. Anhydrous calcium chloride tubes are connected to the end of the combustion tube and the excess hydrogen then ignited at the end of these tubes. Anhydrous calcium chloride absorbs water; the mass of the tubes is determined at the beginning and end of the experiment. The increase in mass of the calcium chloride tubes is equal to the mass of water produced.

Typical results

Mass of water	=	1.125 g
Mass of oxygen (from previous results)	=	1.000 g
Mass of hydrogen	=	0.125 g

	÷ by r.a.m	÷ by smallest	Ratio of atoms
Moles of hydrogen atoms	$\frac{0.125}{1} = 0.125$	$\frac{0.125}{0.0625} = 2$	2
Moles of oxygen atoms	$\frac{1}{16} = 0.0625$	$\frac{0.0625}{0.0625} = 1$	1

Since the ratio of hydrogen to oxygen is 2:1 the simplest (or empirical) formula is H_2O.

In examination calculations of this type the data is often presented not as mass, but as percentage composition of the elements concerned. In these cases the calculation is carried out in an identical fashion as percentage composition is really the mass of the element in 100 g of the compound.

Example 1

Sodium burns in excess oxygen to give a yellow solid oxide that contains 58.97% of sodium. What is the empirical formula of the oxide?

N.B. This is an oxide of sodium. It must contain only Na and O. Since the percentage of Na is 58.97 that of O must be 100 – 58.97 = 41.03%

	÷ by r.a.m	÷ by smallest	Ratio of atoms
Moles of sodium atoms	$\frac{58.97}{23} = 2.564$	$\frac{2.564}{2.564} = 1$	1
Moles of oxygen atoms	$\frac{41.03}{16} = 2.564$	$\frac{2.564}{2.564} = 1$	1

Therefore the empirical formula is **NaO**.

The result of the above calculation does not seem to lead to a recognisable compound of sodium. This is because the method used only gives the **simplest** ratio of the elements - but see below.

Consider the following series of organic compounds:

C_2H_4 ethene, C_3H_6 propene, C_4H_8 butene, C_5H_{10} pentene. These all have the same empirical formula CH_2.

To find the Molecular Formula for a compound it is necessary to know the Relative Molecular Mass (M_r).

Molecular Formula Mass = **Empirical Formula Mass** x **a whole number (n)**

In the example above the oxide has an M_r = 78 g mol^{-1}.

Thus

$$\begin{aligned} \text{Molecular Formula Mass} &= 78 \\ \text{Empirical Formula Mass} &= (Na + O) = 23 + 16 = 39 \\ \therefore 78 &= 39 \times n \\ \therefore n &= 2 \end{aligned}$$

The Molecular Formula becomes **$(NaO)_2$ or Na_2O_2**

Example 2

A compound **P** contains 73.47% carbon and 10.20% hydrogen by mass, the remainder being oxygen. It is found from other sources that **P** has a Relative Molecular Mass of 98 g mol^{-1}. Calculate the molecular formula of **P**.

NB It is not necessary to put in all the details when you carry out a calculation of this type. The following is adequate.

	C	**H**	**O**
	73.47	10.20	(100 – 73.47 – 10.20) = 16.33
By r.a.m	$\frac{73.47}{12}$ = 6.1225	$\frac{10.20}{1}$ = 10.20	$\frac{16.33}{16}$ = 1.020
By smallest	$\frac{6.1255}{1.020}$	$\frac{10.20}{1.020}$	$\frac{1.020}{1.020}$
Ratio of atoms	6	10	1

Therefore the empirical formula is $\mathbf{C_6H_{10}O}$.

To find molecular formula:

Molecular Formula Mass	=	Empirical Formula Mass x whole number (n)
98	=	[(6x12) + (10x1) + 16] x n = 98 x n
$\therefore$ n	=	1

The molecular formula is the same as the empirical formula $\mathbf{C_6H_{10}O}$.

A warning

In calculations of this type at GCE Advanced level you may meet compounds that are different yet have very similar percentage composition of their elements. When you carry out a calculation of this type you should never round up the figures until you get right to the end. For example NH_4OH and NH_2OH have very similar composition and if you round up the data from one you may well get the other. If you are told the Relative Molecular Mass and your Empirical Formula Mass is not a simple multiple of this you are advised to check your calculation.

Example 3

Calculate the empirical formula of a compound with the following percentage composition:

C 39.13%; O 52.17%; H 8.700%

	C	**O**	**H**
By r.a.m	$\frac{39.13}{12}$	$\frac{52.17}{16}$	$\frac{8.700}{1}$
	= 3.26	= 3.25	= 8.70
Divide by smallest	1	1	2.66

It is clear at this stage that dividing by the smallest has not resulted in a simple ratio. **You must not round up or down at this stage**. You must look at the numbers and see if there is some factor that you could multiply each number by to get each one to a whole number. In this case if you multiply each by 3 you will get:

C	**O**	**H**
3	3	8

Thus $\mathbf{C_3H_8O_3}$ is the empirical formulae not $\mathbf{C_1H_{2.66}O_1}$

You need to watch carefully for this, the factors will generally be clear and will be 2 or 3. What you must not do is round 1.33 to 1 or 1.5 to 2.

Calculations involving the moles of water of crystallization

In calculations of this type you need to treat the water as a *molecule* and divide by the *Relative Molecular Mass.*

Example 4

24.6 grams of a hydrated salt of $MgSO_4 . xH_2O$, gives 12.0 g of anhydrous $MgSO_4$ on heating. What is the value of x ?

Your first job is to find the mass of water driven off .

Mass of water evolved = 24.6 – 12.0 = 12.6 g

	$\mathbf{MgSO_4}$	$\mathbf{H_2O}$
	12.0	12.6
Divide by M_r	$\frac{12.0}{120}$	$\frac{12.6}{18}$
	= 0.100	= 0.700
Ratio of Atoms	1	7

Giving a formula of $\mathbf{MgSO_4.7H_2O}$

Exercise 5

Calculation of a formula from experimental data

In *Section a.* calculate the empirical formula of the compound from the data given. This may be as percentage composition or as the masses of materials found in an experiment. For *Section b.* you are given the data for analysis plus the Relative Molecular Mass of the compound, in these cases you are to find the empirical formula and thence the molecular formula. *Section c.* is more difficult, the data is presented in a different fashion but the calculation of the empirical formula/ molecular formula is essentially the same.

Section a

1 Ca 40%; C 12%; O 48%

2 Na 32.4%; S 22.5%; O 45.1%

3 Na 29.1%; S 40.5%; O 30.4%

4 Pb 92.8%; O 7.20%

5 Pb 90.66%; O 9.34%

6 H 3.66%; P 37.8%; O 58.5%

7 H 2.44%; S 39.0%; O 58.5%

8 C 75%; H 25%

9	C 81.81%; H 18.18%
10	H 5.88% ; O 94.12%
11	H 5%; N 35%; O 60%
12	Fe 20.14%; S 11.51%; O 63.31%; H 5.04%

Section b

13	A hydrocarbon with a Relative Molecular Mass (M_r) of 28 g mol^{-1} has the following composition: Carbon 85.7%; Hydrogen 14.3%. Calculate its molecular formula.
14	A hydrocarbon with a Relative Molecular Mass (M_r) of 42 g mol^{-1} has the following composition: Carbon 85.7%; Hydrogen 14.3%. Calculate its molecular formula.
15	P 10.88%; I 89.12%. M_r = 570 g mol^{-1}
16	N 12.28%; H 3.51%; S 28.07%; O 56.14%. M_r = 228 g mol^{-1}
17	P 43.66%; O 56.34%. M_r = 284 g mol^{-1}
18	C 40%; H 6.67%; O 53.3%. M_r = 60 g mol^{-1}
19	Analysis of a compound with a M_r = 58 g mol^{-1} shows that 4.8 g of carbon are joined with 1.0 g of hydrogen. What is the molecular formula of the compound?
20	3.36 g of iron join with 1.44 g of oxygen in an oxide of iron that has a M_r = 160 g mol^{-1} What is the molecular formula of the oxide?
21	A sample of an acid with a M_r = 194 g mol^{-1} has 0.5 g of hydrogen joined to 16 g of sulphur and 32 g of oxygen. What is the molecular formula of the acid?
22	Analysis of a hydrocarbon showed that 7.8 g of the hydrocarbon contained 0.6 g of hydrogen and that the M_r = 78 g mol^{-1}. What is the formula of the hydrocarbon?

Section c

---

23 22.3 g of an oxide of lead produced 20.7 g of metallic lead on reduction with hydrogen. Calculate the empirical formula of the oxide concerned.

---

24 When 1.17 g of potassium is heated in oxygen 2.13 g of an oxide is produced. In the case of this oxide the empirical and molecular formulae are the same. What is the molecular formula of the oxide produced?

---

25 A hydrocarbon containing 92.3% of carbon has a Relative Molecular Mass of 26 g mol^{-1}. What is the molecular formula of the hydrocarbon?

---

26 When 1.335 g of a chloride of aluminium is added to excess silver nitrate solution 4.305 g of silver chloride is produced. Calculate the empirical formula of the chloride of aluminium.

Hint; you will need to work out how much chlorine there is in 4.305 g of AgCl. This will be the amount of chlorine in the initial 1.335 g of the aluminium chloride.

---

27 16 g of a hydrocarbon burn in excess oxygen to produce 44 g of carbon dioxide. What is the empirical formula of the hydrocarbon.

Hint; you will need to work out what mass of carbon is contained in 44 g of CO_2. This is the mass of C in 16 g of the hydrocarbon.

---

28 When an oxide of carbon containing 57.1% oxygen is burnt in air the percentage of oxygen joined to the carbon increases to 72.7%. Show that this data is consistent with the combustion of carbon monoxide to carbon dioxide.

---

29 When 14.97 g of hydrated copper(II) sulphate is heated it produces 9.60 g of anhydrous copper(II) sulphate. What is the formula of the hydrated salt?

---

30 When the chloride of phosphorus containing 85.1% chlorine is heated a second chloride containing 77.5% chlorine is produced. Find the formulae of the chlorides and suggest what the other product of the heating might be.

Section 6

Chemical equations

Chemical equations do much more than tell you what reacts with what in a chemical reaction. They tell you how many of each type of molecule is needed and are produced and so they also tell you what masses of the reactants are needed to produce a given mass of products.

Often you will learn equations that have been given to you. However, if you are to interpret equations correctly you must learn to write them for yourself.

Equations in words

Before you can begin to write an equation, you must know what the reacting chemicals are and what is produced in the reaction. You can then write them down as a *word equation.* For instance, hydrogen reacts with oxygen to give water, or, as a word equation:

Hydrogen + Oxygen → Water

Writing formulae

When you have written the equation in words you can write the formula for each of the substances involved; you may know them or you may have to look them up. In our example:

Hydrogen is represented as H_2;
Oxygen is represented as O_2; and
Water is H_2O.

So we get:

$$H_2 + O_2 \rightarrow H_2O$$

However this will not do as a full equation as you will discover if you read on!

Balancing the equation

One of the most important things you must understand in chemistry is that atoms are **rearranged** in chemical reactions: they are never produced from 'nowhere' and they do not simply 'disappear'. This means that in chemical equation you must have the same number of atoms of each kind on the left-hand side of the equation as on the right. Sometimes you need to start with two or more molecules of one of the reactants and you may end up with more than one molecule of one of the products.

Let us look at two very simple examples:

Carbon + Oxygen → Carbon dioxide

$$C + O_2 \rightarrow CO_2$$

It so happens that carbon dioxide has one atom of carbon and two atoms of oxygen in one molecule: carbon is written as C (one atom) and oxygen molecules have two atoms each: written as O_2.

This equation does not need balancing because the number of atoms of carbon is the same on the left as on the right (1) and the number of atoms oxygen is also the same (2) ie it is already balanced.

Now let us try one that does not work out:

Magnesium + Oxygen $\rightarrow$ Magnesium oxide

Magnesium is written as Mg (one atom just like carbon) and oxygen is, of course, O_2, but magnesium oxide has just one atom of oxygen per molecule and is therefore written as MgO.

So we might write:

$$Mg + O_2 \rightarrow MgO$$

The magnesium balances, one atom on the left and one on the right, but the oxygen does not as there are two atoms on the left-hand side of the equation and only one on the right hand side. **You cannot change the formulae of the reactants or products.**

Each 'formula' of magnesium oxide has only one atom of oxygen: each molecule of oxygen has two atoms of oxygen, so you can make *two* formulae of magnesium oxide for each molecule of oxygen. So we get:

$$Mg + O_2 \rightarrow 2MgO$$

Even now the equation does not balance, because we need two atoms of magnesium to make two formulae of MgO, and the final equation is:

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

Sometimes, you will need to show in the equation whether the chemicals are solid, liquid or gas. You do this by putting in *state symbols*: (aq) for aqueous solution, (g) for gas, (1) for liquid and (s) for solid or precipitate:

$$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$$

Exercise 6a

Balancing equations

Balance the following equations. To get you started _ indicates the first six questions where numbers need to be inserted to achieve the balance. In one or two difficult examples some of the numbers have been added. You will not need to change these. Also remember all the formulae are correct!

1	_ H_2	+	O_2	→	_ H_2O				
2	$BaCl_2$	+	_ NaOH	→	$Ba(OH)_2$	+	_ NaCl		
3	H_2SO_4	+	_ KOH	→	_ K_2SO_4	+	H_2O		
4	K_2CO_3	+	_ HCl	→	_KCl	+	H_2O	+	CO_2
5	$CaCO_3$	+	_HNO_3	→	$Ca(NO_3)_2$	+	H_2O	+	CO_2
6	Ca	+	_H_2O	→	$Ca(OH)_2$	+	H_2		
7	$Pb(NO_3)_2$	+	NaI	→	PbI_2	+	$NaNO_3$		
8	$Al_2(SO_4)_3$	+	NaOH	→	$Al(OH)_3$	+	Na_2SO_4		
9	$Al(OH)_3$	+	NaOH	→	$NaAlO_2$	+	H_2O		
10	$Pb(NO_3)_2$	→	PbO	+	NO_2	+	O_2		

11	$FeSO_4$	$\rightarrow$	Fe_2O_3	+	SO_2	+	SO_3			
12	NH_4NO_3	$\rightarrow$	N_2O	+	H_2O					
13	$NaNO_3$	$\rightarrow$	$NaNO_2$	+	O_2					
14	CH_4	+	O_2	$\rightarrow$	CO_2	+	H_2O			
15	C_4H_{10}	+	O_2	$\rightarrow$	CO_2	+	H_2O			
16	PCl_3	+	H_2O	$\rightarrow$	H_3PO_3	+	HCl			
17	$8HNO_3$	+	3Cu	$\rightarrow$	$Cu(NO_3)_2$	+	NO	+	H_2O	
18	$4HNO_3$	+	Cu	$\rightarrow$	$Cu(NO_3)_2$	+	NO_2	+	H_2O	
19	H_3PO_4	+	NaOH	$\rightarrow$	NaH_2PO_4	+	H_2O			
20	H_3PO_4	+	NaOH	$\rightarrow$	Na_3PO_4	+	H_2O			
21	H_3PO_4	+	NaOH	$\rightarrow$	Na_2HPO_4	+	H_2O			
22	6NaOH	+	Cl_2	$\rightarrow$	$NaClO_3$	+	NaCl	+	H_2O	

23	N_2	+	H_2	→	NH_3							
24	NaBr	+	H_2SO_4	→	Na_2SO_4			+	HBr			
25	HBr	+	H_2SO_4	→	H_2O			+	SO_2		+	Br_2
26	C_2H_5OH	+	PCl_3	→	C_2H_5Cl			+	H_3PO_3			
27	Fe_3O_4	+	H_2	→	Fe			+	H_2O			
28	Fe_2O_3	+	CO	→	Fe			+	CO_2			
29	C_2H_5OH	+	CH_3CO_2H	→	$CH_3CO_2C_2H_5$			+	H_2O			
30	$2KMnO_4$	+	HCl	→	$MnCl_2$	+	Cl_2	+	$8H_2O$		+	KCl

Exercise 6b

What's wrong here?

The following equations have one or more mistakes. These may be in a formula, in the balancing, in the state symbols or even in the chemistry. Your job is to identify the error and then write a correct equation.

1	$Na(s)$	+	$H_2O(l)$	→	$NaOH(aq)$	+	$H(g)$			
2	$PbNO_3(aq)$	+	$NaCl(aq)$	→	$PbCl(s)$	+	$NaNO_3(aq)$			
3	$CaOH_2(aq)$	+	$2HCl(aq)$	→	$CaCl_2(aq)$	+	$2H_2O(l)$			
4	$C_2H_4(g)$	+	$2O_2(g)$	→	$2CO_2(g)$	+	$2H_2(g)$			
5	$MgSO_4(aq)$	+	$2NaOH$	→	$Ca(OH)_2(s)$	+	$Na_2SO_4(aq)$			
6	$Cu(NO_3)_2(s)$	+	$CuO(s)$	→	$2NO(g)$	+	$O_3(g)$			
7	$Cu(s)$	+	$H_2SO_4(aq)$	→	$CuSO_4(aq)$	+	$H_2(g)$			
8	$AlCl_2(s)$	+	$2KOH(aq)$	→	$Al(OH)_2(s)$	+	$2KCl(aq)$			
9	$NaCO_3(s)$	+	$2HCl(aq)$	→	$NaCl_2(aq)$	+	$CO_2(g)$	+	$H_2O(l)$	
10	$2AgNO_3(aq)$	+	$MgCl_2(aq)$	→	$Mg(NO_3)_2(s)$	+	$2AgCl(aq)$			

Exercise 6c

Writing equations in symbols from equations in words

In the following examples you will need to convert the names of the materials into formulae and then balance the resulting equation. In some cases more than one experiment is described. In these cases you will need to write more than one equation.

---

1 Zinc metal reacts with copper sulphate solution to produce solid copper metal and zinc sulphate solution.

---

2 Solid calcium hydroxide reacts with solid ammonium chloride on heating to produce solid calcium chloride, steam and ammonia gas.

---

3 When lead(II) nitrate is heated in a dry tube lead(II) oxide, nitrogen dioxide gas and oxygen are produced.

---

4 Silicon tetrachloride reacts with water to produce solid silicon dioxide and hydrogen chloride gas.

---

5 When a solution of calcium hydrogen carbonate is heated a precipitate of calcium carbonate is produced together with carbon dioxide gas and more water.

---

6 When octane (C_8H_{18}) vapour is burnt with excess air in a car engine carbon dioxide and water vapour are produced.

---

7 All the halogens, apart from fluorine, react with concentrated sodium hydroxide solution to produce a solution of the sodium halide (NaX) the sodium halate ($NaXO_3$) and water.

---

8 The elements of Group 1 of the periodic table all react with water to produce a solution of the hydroxide of the metal and hydrogen gas.

The last two examples in this section will need a lot of thought as they involve changes in the valency of the elements concerned. Before you start to balance the equations check with your teacher that you have the formulae correct.

---

8 Tin(II) chloride solution reacts with mercury(II) chloride solution to produce a precipitate of mercury(I) chloride and a solution of tin(IV) chloride. This precipitate of mercury(I) chloride then reacts with further tin(II) chloride solution to produce liquid mercury and more tin(IV) chloride solution.

9 Concentrated sulphuric acid reacts with solid potassium iodide to produce solid potassium hydrogen sulphate, iodine vapour, water and hydrogen sulphide gas.

Section 7

How equations are found by experiment

Although equations are often printed in books for you to learn, you must remember that they have all been found originally by someone doing experiments to measure how much of each chemical reacted and how much of each product was formed.

Below are set out some of the methods you could use:

- *Direct mass determinations*, eg the reaction of magnesium with oxygen

A known mass of magnesium is heated in a crucible to constant mass and hence the mass of magnesium oxide is found. Supposing 0.12 g of magnesium produce 0.20 g of magnesium oxide. By subtraction, the mass of oxygen combined with the magnesium is 0.080 g.

Each of these masses is then converted to moles and it is found that every 2 moles of magnesium react with one mole oxygen molecules and produce two moles of magnesium oxide: hence

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

- *Reacting volumes in solution*: usually you have to calculate concentrations of acids or alkalis by reaction with the appropriate standard solution and use the chemical equation for the reaction

However, you can calculate the ratio of reacting moles from experimental data, in order to construct the equation. To do this you use solutions, both of whose concentrations you know. You then do a titration in the usual way and use the volumes used in the titration to find the number of moles of each reagent which react.

These are then used in the equation straight away, just as in the magnesium oxide example above.

- *Measurement of gas volumes*: the molar volume of a gas is taken as 24 dm^3 at room temperature and atmospheric pressure (r.t.p.)

Examples

1 In an experiment a solution containing 3.31 g of lead(II) nitrate reacts with a solution containing 1.17 g of sodium chloride to produce 2.78 g of lead(II) chloride solid and leave a solution that contains 1.70 g of sodium nitrate. What is the equation for the reaction?

In this type of question you are required to calculate the ratio of the reacting moles and then use these to write the equation.

$Pb(NO_3)_2$	$NaCl$	$PbCl_2$	$NaNO_3$
$M_r = 331$	$M_r = 58.5$	$M_r = 278$	$M_r = 85$

∴	3.31 g of $Pb(NO_3)_2$	= (3.31/331) mol	= 0.010 mol
	1.17 g of NaCl	= (1.17/58.5) mol	= 0.020 mol
	2.78 g of $PbCl_2$	= (2.78/278) mol	= 0.010 mol
	1.70 g of $NaNO_3$	= (1.70/85) mol	= 0.020 mol

∴ 0.01 mol of $Pb(NO_3)_2$ reacts with 0.02 mol of NaCl to give 0.01 mol of $PbCl_2$ and 0.02 mol of $NaNO_3$

ie 1 mol of $Pb(NO_3)_2$ reacts with 2 mol of NaCl to give 1 mol of $PbCl_2$ and 2 mol of $NaNO_3$

$$\mathbf{Pb(NO_3)_2 + 2NaCl \rightarrow PbCl_2 + 2NaNO_3}$$

It is not necessary to write all of this out each time.

2 When 5.175 g of lead are heated at 300°C the lead reacts with the oxygen in the air to produce 5.708 g of an oxide of lead. This is the only product. What is the equation for this reaction? *In a question of this type you seem to be short of information but in fact you know the mass of oxygen reacting. Remember this is oxygen molecules that are reacting not oxygen atoms.*

Mass of oxygen used is 5.708 – 5.175 g = 0.533 g

Moles of lead reacting	= (5.175/207) mol	= 0.025 mol
Moles of oxygen reacting	= (0.533/32) mol	= 0.0167 mol

∴ 0.025 mol of Pb react with 0.0167 mol of O_2 to give product

∴ 1.5 mol of Pb react with 1 mol of O_2 to give product

∴ 3 mol of Pb react with 2 mol of O_2 to give product

$$\mathbf{3Pb + 2O_2 \rightarrow Pb_3O_4}$$

You do not have the information to write the full equation but as you know there is only one product and this has 3 lead atoms and 4 oxygen you can suggest a formula.

3 25 cm^3 of 2M sulphuric acid solution react with 50 cm^3 of 2M sodium hydroxide solution to produce sodium sulphate and water. Construct the equation for this reaction.

You will need to look at the start of chapter 11 before you can follow this question.

25 cm^3 of 2M H_2SO_4 contain (25 x 2/1000) mol of H_2SO_4 = 0.050 mol

50 cm^3 of 2M NaOH contain (50 x 2/1000) mol of NaOH = 0.10 mol

$\therefore$ 0.05 mol of H_2SO_4 react with 0.10 mol of NaOH to give Na_2SO_4 plus H_2O

$\therefore$ 1 mol of H_2SO_4 react with 2 mol of NaOH to give Na_2SO_4 plus H_2O

$$\mathbf{H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O}$$

4 2 cm^3 of nitrogen gas react completely with 6 cm^3 of hydrogen gas to produce 4cm^3 of ammonia gas. Use the data to write the equation for this reaction.

2 cm^3 of nitrogen	= (2/24000) mol	= 8.33×10^{-5} mol
6 cm^3 of hydrogen	= (6/24000) mol	= 2.50×10^{-4} mol
4 cm^3 of ammonia	= (4/24000) mol	= 1.67×10^{-4} mol

$\therefore$ ratios are	($8.33 \times 10^{-5}/8.33 \times 10^{-5}$) of nitrogen	= 1
	($2.50 \times 10^{-4}/8.33 \times 10^{-5}$) of hydrogen	= 3
	($1.67 \times 10^{-4}/8.33 \times 10^{-5}$) of ammonia	= 2

$$\mathbf{N_2 + 3H_2 \rightarrow 2NH_3}$$

5 1 g of $CaCO_3$ reacts with 10 cm^3 of 2M HNO_3 to produce 1.64 g of $Ca(NO_3)_2$, 240 cm^3 of CO_2 and water.

In practice the acid will be in water and it is almost impossible to measure the amount of water produced by the reaction.

	1/ 100 mol of $CaCO_3$	+	(10x2)/1000 mol of HNO_3	$\rightarrow$	1.64/164 mol of $Ca(NO_3)_2$	+	240/24000 mol of CO_2	+	H_2O
$\therefore$	0.01 mol of $CaCO_3$	+	0.02 mol of HNO_3	$\rightarrow$	0.01 mol of $Ca(NO_3)_2$	+	0.01 mol of CO_2	+	H_2O
	$CaCO_3$	+	**$2HNO_3$**	$\rightarrow$	**$Ca(NO_3)_2$**	+	**CO_2**	+	**H_2O**

Exercise 7

Writing chemical equations from experimental data

Use the data below to write the equations for the reactions listed. In some cases you may not be able to calculate the moles of all the materials involved. In these cases you should indicate that you have 'balanced' this part yourself.

In examples involving gases you should assume 1 Mole of gas occupies 24 000 cm^3 at room temperature and pressure.

1 In an experiment a solution containing 6.675 g of aluminium chloride reacted with a solution containing 25.50 g of silver nitrate. 21.52 g of silver chloride was produced together with a solution of 10.65 g of aluminium nitrate, $Al(NO_3)_3$. What is the equation for the reaction taking place?

2 100 cm^3 of a solution of potassium chromate(VI), containing 97.05 g dm^{-3}, reacts with 50 cm^3 of a solution, containing 331 g dm^{-3} of lead nitrate, to produce 16.15 g of a precipitate of lead(II) chromate and 150 cm^3 of a solution of potassium nitrate, which gives 10.1 g of solid when the water is evaporated off from the solution. Write the equation for the reaction.

3 1.133 g of silver nitrate was heated in an open tube. The silver residue weighed 0.720 g. During the reaction 0.307 g of nitrogen dioxide was also produced. The rest of the mass loss was due to oxygen. Use the data to write the equation for the reaction.

4 In a titration using methyl orange as an indicator 25.0 cm^3 of a solution of 0.1 M sodium hydroxide reacted with 25.0 cm^3 of 0.1 M phosphoric acid, H_3PO_4, solution. If the experiment is repeated using phenolphthalein in place of the methyl orange as the indicator the volume of the sodium hydroxide used to cause the indicator to change colour is 50.0 cm^3.

i Use the data to calculate the number of moles of sodium hydroxide that reacts with one mole of phosphoric acid in each case

ii Suggest the formula of the salt produced in each case

iii Write the equations

iv What volume of the alkali would be needed to produce the salt Na_3PO_4?

5 50 cm^3 of a solution of citric acid, M_r = 192, containing 19.2 g dm^{-3} reacted with 50 cm^3 of a solution of sodium hydroxide containing 12 g dm^{-3}. Citric acid can be represented by the formula H_xA, where x represents the number of hydrogen atoms in the molecule. Use the data above to calculate the number of moles of sodium hydroxide that react with one mole of citric acid and hence find the value of x.

---

6 When 12.475 g of hydrated copper(II) sulphate, $CuSO_4.xH_2O$, was heated 7.980 g of anhydrous salt were produced. Use the data to find the value of x and hence write the equation for the reaction.

---

7 When 20 cm^3 ammonia gas is passed over a catalyst with excess oxygen 20 cm^3 of nitrogen monoxide (NO) and 30 cm^3 of water vapour are produced. Use this data to write the equation for the reaction.

---

8 10 cm^3 of a hydrocarbon C_aH_b reacted with 50 cm^3 of oxygen gas to produce 30 cm^3 of carbon dioxide and 40 cm^3 of water vapour. Use the data to calculate to reacting moles in the equation and suggest value for a and b.

---

9 When 8.4 g of sodium hydrogen carbonate are heated 5.30 g of solid residue are produced 1200 cm^3 of carbon dioxide are produced and 0.900 g of water are evolved. Show that this data is consistent with the following equation.

$$2NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$$

---

10 When 13.9 g of $FeSO_4.xH_2O$ is heated 4 g of solid iron (III) oxide is produced together with the loss of 1.6 g of sulphur dioxide and 2.0 g of sulphur trioxide. The rest of the mass loss being due to the water of crystallization being lost. Use the data to write the full equation for the action of heat.

Section 8

Amounts of substances

Equations can also tell you how much of a chemical is reacting or is produced. The equation in *Section 7* tells us that 2 moles of (solid) magnesium atoms react with 1 mole of (gaseous) oxygen molecules to produce 2 moles of (solid) magnesium oxide molecules.

We know that the relative atomic mass of magnesium is 24, and that of oxygen is 16, (see periodic table on page 113). And from the equation we balanced in *Section 6* we can suggest that 48 g of magnesium react with 32 g of oxygen (because an oxygen molecule contains two atoms) to give 80 g of magnesium oxide.

Since we know the ratio of reacting masses (or volumes in the case of gases) we can calculate any reacting quantities based on the equation.

Example 1

a What mass of magnesium oxide would be produced from 16 g of magnesium in the reaction between magnesium and oxygen?

i Write the full balanced equation

$$2Mg(s) \quad + \quad O_2(g) \quad \rightarrow \quad 2MgO(s)$$

ii Read the equation in terms of moles

2 moles of magnesium reacts to give 2 moles of magnesium oxide

iii Convert the moles to masses using the M_r values

∴ (2 x 24g) of magnesium gives 2 x (24+16) = 80 g of Magnesium oxide

∴ 16 g of magnesium gives $\frac{80 \times 16}{2 \times 24}$ = **26.7 g of Magnesium oxide** b What volume of oxygen would react with 16 g of magnesium in the above reaction?

In this case the oxygen is a gas so the volume of each mole is 24000 cm^3 at room temperature and pressure and you do not have to worry about the molecular mass of the gas.

From the equation:

2 moles of Mg reacts with 1 mole of O_2

$\therefore$ 2 x 24 g of Mg reacts with 1 x 24000 cm^3 of O_2(g)

$\therefore$ 16 g of Mg reacts with $\frac{1 \times 24\,000\,\text{cm}^3 \times 16\,\text{g}}{2 \times 24\,\text{g}}$ = **8000 cm^3 of oxygen**

Example 2

What mass of lead(II) sulphate would be produced by the action of excess dilute sulphuric acid on 10 g of lead nitrate dissolved in water ?

$$Pb(NO_3)_2(aq) + H_2SO_4(aq) \rightarrow PbSO_4(s) + 2HNO_3(aq)$$

$\therefore$ 1 mole of lead nitrate gives 1 mole of lead sulphate

$\therefore$ 331 g of lead nitrate gives 303 g of lead sulphate

$\therefore$ 10 g of lead nitrate gives $\frac{303\,\text{g} \times 10\,\text{g of lead sulphate}}{331\,\text{g}}$ = **9.15 g of lead sulphate**

Example 3

What is the total volume of gas produced by the action of heat on 1 g of silver nitrate?

$$2AgNO_3(s) \rightarrow 2Ag(s) + 2NO_2(g) + O_2(g)$$

2 moles of silver nitrate give 2 moles of nitrogen dioxide gas plus 1 mole of oxygen gas = 3 moles of gas

$\therefore$ 2 x 170 g of silver nitrate give 3 x 24000 cm^3 of gas

$\therefore$ 1 g of silver nitrate gives $\frac{3 \times 24\,000\,\text{cm}^3 \times 1\,\text{g of gas}}{2 \times 170\,\text{g}}$ = **211.8 cm^3 of gas**

Example 4

When excess carbon dioxide is passed into sodium hydroxide solution, sodium carbonate solution is formed. This can be crystallised out as $Na_2CO_3.10H_2O$. What mass of crystals would be produced from 5 g of sodium hydroxide in excess water.

Care. You need the water as moles in the equation.

$$2NaOH(aq) \quad + \quad CO_2(g) \quad + \quad 9H_2O \quad \rightarrow \quad Na_2CO_3(aq) \quad + \quad 10H_2O(l) \quad \rightarrow \quad Na_2CO_3.10H_2O(s)$$

∴ 2 moles of sodium hydroxide give 1 mole of the crystals of sodium carbonate

∴ 2 x 40 g of sodium hydroxide give 286 g of crystals

∴ 5 g of sodium hydroxide give $\dfrac{286 \times 5}{2 \times 40}$ = **17.88 g of crystals**

Example 5

What mass of ethanoic acid and what mass of ethanol would be needed to produce 100 g of ethyl ethanoate assuming the reaction went to completion?

Care! In this question you know how much you want to get and are asked how much you will need to start with. In these cases you must read the equation from the other end ie 1 mole of the ethyl ethanoate is produced from 1 mole of acid and 1 mole of alcohol.

$CH_3CO_2H(l)$	+	$C_2H_5OH(l)$	→	$CH_3CO_2C_2H_5(l)$	+	$H_2O(l)$
(12+3+12+32+1)		(24+5+16+1)		(12+3+12+32+24+5)		
= 60		= 46		= 88		

∴ 88 g of ethyl ethanoate are produced from 60 g of ethanoic acid and 46 g of ethanol

∴ 100 g of ethyl ethanoate are produced from $\dfrac{60\,g \times 100\,g}{88\,g}$ = **68.2 g of ethanoic acid**

and $\dfrac{46\,g \times 100\,g}{88\,g}$ = **52.3 g of ethanoic acid**

Exercise 8

Calculations of products/reactants based on equations

In this exercise the equations you need are given in the question, unless they were included in Exercise 6a.

1 What mass of barium sulphate would be produced from 10 g of barium chloride in the following reaction?

$$BaCl_2 + H_2SO_4 \rightarrow BaSO_4 + 2HCl$$

2 What mass of potassium chloride would be produced from 20 g of potassium carbonate?

3 What masses of ethanol and ethanoic acid would need to be reacted together to give 1 g of ethyl ethanoate?

4 What mass of iron(III) oxide would need to be reduced to produce 100 tonnes of iron in a blast furnace?

5 What mass of silver nitrate as a solution in water would need to be added to 5 g of sodium chloride to ensure complete precipitation of the chloride?

$$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$

6 A solution of copper sulphate reacts with sodium hydroxide solution to produce a precipitate of copper hydroxide according to the following equation:

$$CuSO_4(aq) + 2NaOH(aq) \rightarrow Cu(OH)_2(s) + Na_2SO_4(aq)$$

What mass of sodium hydroxide would be needed to convert 15.95 g of copper sulphate to copper hydroxide and what mass of copper hydroxide would be produced?

7 What volume of ammonia gas would be needed to produce 40 g of ammonium nitrate in the following reaction?

$$NH_3(g) + HNO_3(aq) \rightarrow NH_4NO_3(aq)$$

8 In the reaction between calcium carbonate and nitric acid what mass of calcium nitrate and what volume of carbon dioxide would be produced from 33.3 g of calcium carbonate?

9	What would be the total volume of gas produced by the action of heat on 33.1 g of lead(II) nitrate ?
10	Magnesium reacts with sulphuric acid to produce a solution of magnesium sulphate. If this is allowed to crystallise out the solid produced has the formula $MgSO_4.7H_2O$. Write the equation for this reaction and calculate the mass of magnesium sulphate heptahydrate that could be produced from 4 g of magnesium.
11	Copper(II) oxide reacts with sulphuric acid to produce copper(II) sulphate. If this is allowed to crystallise the formula of the crystals is $CuSO_4.5H_2O$. What mass of copper oxide would be needed to produce 100 g of crystals?
12	Sulphur dioxide can be removed from the waste gases of a power station by passing it through a slurry of calcium hydroxide. The equation for this reaction is: $SO_2(g) + Ca(OH)_2(aq) \rightarrow CaSO_3(aq) + H_2O(l)$ What mass of calcium hydroxide would be needed to deal with 1000 dm^3 of sulphur dioxide?
13	In a fermentation reaction glucose is converted to alcohol and carbon dioxide according to the following equation: $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$ What mass of alcohol and what volume of carbon dioxide would be produced from 10 g of glucose?
14	In the following reactions calculate the mass of precipitate formed from 20 g of the metal salt in each case.

(i)	$ZnSO_4(aq)$	+	2NaOH	$\rightarrow$	$Zn(OH)_2(s)$	+	$Na_2SO_4(aq)$
(ii)	$Al_2(SO_4)_3(aq)$	+	6NaOH	$\rightarrow$	$2\ Al(OH)_3(s)$	+	$3Na_2SO_4(aq)$
(iii)	$MgSO_4(aq)$	+	2NaOH	$\rightarrow$	$Mg(OH)_2(s)$	+	$Na_2SO_4(aq)$

15	What volume of hydrogen would be produced by 1 g of calcium in its reaction with water?
16	What mass of magnesium would be needed to produce 100 cm^3 of hydrogen?

17	Chlorine reacts with sodium hydroxide as follows: $Cl_2(g) + 6NaOH(aq) \rightarrow 5NaCl(aq) + NaClO_3(aq) + 3H_2O(l)$ What mass of sodium chloride and what mass of sodium chlorate(V) be produced from 240 cm^3 of chlorine gas?
18	When nitrogen reacts with hydrogen in the Haber Process only 17% of the nitrogen is converted to ammonia. What volume of nitrogen and what volume of hydrogen would be needed to produce 1 tonne of ammonia? (1 tonne = 1 x 10^6 g)
19	Nitric acid is produced by the following series of reactions: $4NH_3 + 5O_2 \rightarrow 4NO + 3H_2O$ $4NO + O_2 \rightarrow 4NO_2$ $4NO_2 + O_2 + 2H_2O \rightarrow 4HNO_3$ What mass of nitric acid would be produced from 17 tonnes of ammonia and what volume of oxygen would be needed in the reaction?
20	Hardness in water is caused by dissolved calcium compounds. When heated some of these break down and deposits calcium carbonate as follows: $Ca(HCO_3)_2 \rightarrow CaCO_3 + H_2O + CO_2$ This builds up as 'fur' on the inside of boilers. It can be removed by reaction with hydrochloric acid. What mass of calcium carbonate would be produced from 10000 dm^3 of water containing 0.356 g of calcium hydrogen carbonate per dm^3 of water and what volume of 10 mol dm^{-3} hydrochloric acid solution would be needed to remove the solid calcium carbonate from the inside of the boiler?

Section 9

Reactions involving gases

Whenever gases are involved in a reaction you need to remember that they have both mass and volume and that **1 mole of any gas has the same volume, 24 000 cm^3, at room temperature and 1 atmosphere pressure as 1 mole of any other gas**. (See *Section 4* for more details)

This means:

2 g of hydrogen, H_2, has a volume of 24 000 cm^3

32 g of oxygen, O_2, has a volume of 24 000 cm^3

81 g of hydrogen bromide, HBr, has a volume of 24 000 cm^3

The effect of this is to make calculations involving gas volumes much easier than you might expect.

Consider the following reaction:

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

This says:

2 moles of NO(g) react with 1 mole of O_2(g) to give 2 moles of NO_2(g)

$\therefore$ (2 x 24 000) cm^3 of NO react with (1 x 24 000) cm^3 of oxygen to give (2 x 24 000) cm^3 of NO_2

2 cm^3 of NO react with 1 cm^3 of oxygen to give 2 cm^3 of NO_2

ie for gases only the reacting volume ratios are the same as the reacting mole ratios in the equation.

Example 1

What volume of sulphur trioxide would be produced by the complete reaction of 100 cm^3 of sulphur dioxide with oxygen? What volume of oxygen would be needed to just react with the sulphur dioxide?

	$2SO_2(g)$	+	$O_2(g)$	$\rightarrow$	$2SO_3(g)$
Ratios	2		1		2
ie	1		½		1
	100 cm^3		50 cm^3		100 cm^3

Thus 100 cm^3 of sulphur dioxide will need 50 cm^3 of oxygen and produce 100 cm^3 of sulphur dioxide.

Example 2

What would be the composition of the final product in Example 1 if 100 cm^3 of oxygen had been used rather than 50 cm^3?

Since 100 cm^3 of the sulphur dioxide needs only 50 cm^3 of oxygen there must be 50 cm^3 of oxygen unused. Thus the final volume is:

100 cm^3 of sulphur dioxide plus 50 cm^3 of excess oxygen = 150 cm^3

Example 3

What volume of ammonia would be produced if 10 cm^3 of nitrogen was reacted with 20 cm^3 of hydrogen?

$$N_2(g) \quad + \quad 3H_2(g) \quad \rightarrow \quad 2NH_3(g)$$

You need to think before you start this question. The reacting volumes given in the question are not the same as those in the reaction. You must have excess of one of the gases.

From the equation:

10 cm^3 of nitrogen needs 30 cm^3 of hydrogen. You only have 20 cm^3 of hydrogen so the nitrogen is in excess**.**

In this case you will need to use the hydrogen volume in the calculation.

	$N_2(g)$	+	$3H_2(g)$	→	$2NH_3(g)$
Ratios	1		3		2
	1/3		1		2/3
	1/3 x 20		20		2/3 x 20
	6.67 cm^3		20 cm^3		13.33 cm^3

Thus 20 cm^3 of hydrogen will react to give **13.33 cm^3 of ammonia** and there will be 3.33 cm^3 of hydrogen left over.

Exercise 9

Calculations based on equations involving only gases

Section a

In *Section a*. assume that you have 10 cm^3 of the first named reactant and then calculate the volumes of all the gases involved in the equation. In these examples the reactions are being carried out at above 100°C and you should assume the water is present as a gas and therefore has a volume.

1	CH_4	+	$2O_2$	→	CO_2	+	$2H_2O$
2	C_2H_4	+	$3O_2$	→	$2CO_2$	+	$2H_2O$
3	$2C_2H_2$	+	$5O_2$	→	$4CO_2$	+	$2H_2O$
4	$2C_8H_{18}$	+	$25O_2$	→	$16CO_2$	+	$18H_2O$
5	N_2	+	$3H_2$	→	$2NH_3$		

Section b

In *Section b.* you are asked to find the total volume of gas produced at room temperature and pressure. You should ignore the volume of water produced as this will have condensed as a liquid. Be careful in some cases, as there is an excess of one of the reactants.

1 What volume of oxygen would be needed to convert 1000 cm^3 of nitrogen monoxide, NO, to nitrogen dioxide, NO_2? (Assume all volumes are measured at the same temperature and pressure.)

2 In the production of sulphuric acid sulphur dioxide is converted to sulphur trioxide by reaction with the oxygen in the air. What volume of air (assume 20% of the air is oxygen) would be needed to produce 150 cm^3 of sulphur trioxide? Assume complete conversion of sulphur dioxide to sulphur trioxide.

3 In equation for the oxidation of ammonia to nitrogen monoxide is:

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$$

What volume of ammonia would be required to produce 2500 cm^3 of nitrogen monoxide and what volume of air would be used in the conversion? Again assume that air is 20% oxygen by volume.

4 What volume of oxygen at room temperature and pressure would be needed to completely burn 1 mole of butane?

5 What volume of hydrogen at room temperature and pressure would be needed to convert 1 mole of ethene, C_2H_4, to ethane, C_2H_6?

6 What is the final volume of gas produced at room temperature when 10 cm^3 of methane is burnt with 30 cm^3 of oxygen?

7 What is the final volume of gas produced at room temperature if 5 cm^3 of octane are burnt with 100 cm^3 of oxygen?

8	In a reaction between methane and oxygen 60 cm^3 of methane was burnt with 60 cm^3 of oxygen. What is the composition of the gas mixture produced?
9	What volume of ammonia would be produced if 10 cm^3 of nitrogen was reacted with 60 cm^3 of hydrogen?
10	What would be the final volume of gas produced in the reaction between 10 cm^3 of hydrogen and 10 cm^3 of oxygen?

Section 10

Ions and ionic equations

Ionic theory

Many of the chemicals which you will use at GCE Advanced are ionic, that is the chemical bonds which hold the atoms together are ionic bonds. When you melt these compounds the ions are free to move and this gives them some special properties. Often, but not always, these chemicals are soluble in water and when they dissolve the ions separate to produce a solution containing positive and negative ions.

A few covalent substances also form ions when they dissolve in water. Some of these are extremely important: hydrogen chloride and sulphuric acid are examples.

Structures of ionic compounds

In your course you will study bonding and structure, but at a of the most important ideas are set out below.

- Ions are atoms or groups of atoms, which have a positive or negative electric charge.
- Positive ions are called cations (pronounced cat-ions) and negative ions are called anions (pronounced an-ions).
- Positive ions attract negative ions all around them and are firmly held in a rigid lattice; this is what makes ionic compounds solids.
- When an ionic compound is solid it is crystalline, but when it melts or is dissolved in water the ions become free and can move around.
- Ions have *completely* different properties from the atoms in them; chlorine is an extremely poisonous gas, but chloride ions are found in sodium chloride, which is essential to human life.

Ionic equations and spectator ions

Many of the chemicals, which you study are *ionic*, and in these cases it is the ions which react, not the molecules. For instance, copper(II) sulphate is usually written as $CuSO_4$ but it is more often the ion Cu^{2+} which reacts. When you write an ionic equation you include only the ions which **actually take part in the reaction**.

Let us look at molecular equation and see how it may be converted into an ionic equation. For example, look at the reaction between iron(II) sulphate solution and aqueous sodium hydroxide.

$$FeSO_4(aq) \quad + \quad 2NaOH(aq) \quad \rightarrow \quad Fe(OH)_2(s) \quad + \quad Na_2SO_4(aq)$$

In water, the iron (II) sulphate and the sodium hydroxide are in the form of freely moving ions. When the two solutions are mixed together, we see a green precipitate of iron (II) hydroxide solid. Remaining in solution will be a mixture of sodium ions and sulphate ions.

$$Fe^{2+}(aq) \quad + \quad 2OH^{-}(aq) \quad \rightarrow \quad Fe(OH)_2(s)$$

Also when silver nitrate solution reacts with sodium chloride solution the changes do not involve the nitrate ion from the silver nitrate or the sodium ion from the sodium chloride. These are referred to as ‘spectator ions’. The equation for this reaction can be written

$$Ag^{+}(aq) \quad + \quad Cl^{-}(aq) \quad \rightarrow \quad AgCl(s)$$

This equation represents the reaction between **any** aqueous solution containing silver ions and **any** aqueous solution containing chloride ions. This is the equation for the test for a chloride ion in solution.

You can work out an ionic equation as follows using the example of the reaction of iron(II) sulphate solution with excess sodium hydroxide solution.

1 Write down the balanced molecular equation

$$FeSO_4(aq) \quad + \quad 2NaOH(aq) \quad \rightarrow \quad Fe(OH)_2(s) \quad + \quad Na_2SO_4(aq)$$

2 Convert those chemicals that are ions **in solution** into their ions

$$Fe^{2+}(aq) + \cancel{SO_4}^{2-}(aq) + \cancel{2Na}^{+}(aq) + 2OH^{-}(aq) \rightarrow Fe(OH)_2(aq) + \cancel{2Na}^{+}(aq) + \cancel{SO_4}^{2-}(aq)$$

3 Cross out those ions that appear on both sides of the equation as they have not changed during the reaction. They started in solution and they finished in the solution. To give the ionic equation:

$$Fe^{2+}(aq) \quad + \quad 2OH^{-}(aq) \quad \rightarrow \quad Fe(OH)_2(s)$$

Check that the atoms **and** the charges balance.

Exercise 10

Ionic equations

In questions 1–5 you are required to balance the equations, in questions 6–10 you are required to complete the equation and then balance it. For questions 1–17 you are required to write the full, balanced ionic equation. Questions 18–20 involve more complex ions again you are just asked to balance the equation.

1	$Pb^{2+}(aq)$	+	$OH^-(aq)$	$\rightarrow$	$Pb(OH)_2(s)$					
2	$Al^{3+}(aq)$	+	$OH^-(aq)$	$\rightarrow$	$Al(OH)_3(s)$					
3	$Al(OH)_3(s)$	+	$OH^-(aq)$	$\rightarrow$	$AlO_2^{2-}(aq)$	+	$H_2O(l)$			
4	$Cl_2(g)$	+	$OH^-(aq)$	$\rightarrow$	$ClO_3^{3-}(aq)$	+	$Cl^-(aq)$	+	$H_2O(l)$	
5	$S_2O_3^{2-}(aq)$	+	$I_2(s)$	$\rightarrow$	$S_4O_6^{2-}(aq)$	+	$2I^-(aq)$			
6	$Cu^{2+}(aq)$	+	$OH^-(aq)$	$\rightarrow$						
7	$CO_3^{2-}(s)$	+	$H^+(aq)$	$\rightarrow$						
8	$Zn(s)$	+	$H^+(aq)$	$\rightarrow$						
9	$Zn(s)$	+	$Pb^{2+}(aq)$	$\rightarrow$						
10	$H^+(aq)$	+	$OH^-(aq)$	$\rightarrow$						

11 Write an ionic equation for the reaction of magnesium with sulphuric acid.

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12 Write an ionic equation for the reaction of sodium carbonate solution with nitric acid.

---

13 Write an ionic equation for the reaction of copper oxide with hydrochloric acid.

---

14 Write an ionic equation for the reaction of barium chloride solution with sodium sulphate solution.

---

15 Write an ionic equation for the reaction of silver nitrate solution with potassium chloride solution.

---

16 Write an ionic equation for the reaction of zinc with silver nitrate solution.

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17 Write ionic equations for the reactions of sodium hydroxide and potassium hydroxide with hydrochloric acid.

---

18 Write ionic equations for the reactions of sodium hydroxide and potassium hydroxide with nitric acid.

---

19 Write ionic equations for the reactions of sodium hydroxide and potassium hydroxide with sulphuric acid.

---

20 What do you notice about the answers to questions 17, 18 and 19?

Section 11

Calculations involving chemicals in solution

These are often referred to as Volumetric Analysis. The name should not worry you, the basis of the calculations is the same as all the rest ie moles and equations.

Many reactions take place in solution involving solutions of known concentration.

Concentration in solution is generally measured as moles per 1000 cm^3 **of solution**. For example the sodium chloride on the bench may be labelled as 1M NaCl. This means that each 1000 cm^3 of the solution contains 1 Mole of NaCl (58.5 g).

It does not mean that 58.5 g of NaCl have been added to 1000 cm^3 of water.

The solution will have been made up by measuring out 58.5 g of the solid, dissolving it in about 500 cm^3 of water and then adding water to make the total volume of the mixture up to 1000 cm^3. (1 dm^3)

Concentration in mol dm^{-3} is called **molarity**.

$$\textbf{molarity} = \frac{\textbf{concentration in grams per 1000 cm}^3}{\textbf{M}_\textbf{r}\textbf{ for the material dissolved}}$$

$$\text{number of moles of material in a given volume} = \frac{\text{molarity} \times \text{volume}(\text{cm}^3)}{1000}$$

$$\text{mass of material in a given volume of solution} = \frac{\text{molarity} \times \text{volume}(\text{cm}^3) \times \text{M}_\text{r}}{1000}$$

In reactions in solution it is often more convenient to use molarity rather than g dm^{-3}.

There are two ways you can approach calculations involving solutions. The first method (A) detailed below is really a short cut way of using the more detailed method B. Most of the straight forward calculations you will meet at the start of your course and the ones in this booklet can be carried through using method A.

Method A

Consider the following reaction between two solutions

$$aA(aq) \quad + \quad bB(aq) \quad \rightarrow \quad cC(aq) \quad + \quad dD(aq)$$

In this reaction a moles of substance A react with b moles of substance B

Let us suppose that V_a cm^3 of the solution of A react with V_b cm^3 of the solution of B. If this is an acid/alkali reaction we could find these volumes out using an indicator.

$\therefore$ Number of moles of A in V_a cm^3 of solution $= \dfrac{V_a M_a}{1000} = a$

$\therefore$ Number of moles of B in V_b cm^3 of solution $= \dfrac{V_b M_b}{1000} = b$

$\therefore$ If we divide equation (i) by equation (ii) we get

$$\boxed{\frac{V_a M_a}{V_b M_b} = \frac{a}{b}}$$

This relationship will hold good for any reaction between two **solutions.**

Examples

1 $2NaOH(aq) \quad + \quad H_2SO_4(aq) \quad \rightarrow \quad Na_2SO_4(aq) \quad + \quad 2H_2O(l)$

$$\frac{M_{NaOH} \times V_{NaOH}}{M_{H_2SO_4} \times V_{H_2SO_4}} = \frac{2}{1}$$

2 $BaCl_2(aq) \quad + \quad H_2SO_4(aq) \quad \rightarrow \quad BaSO_4(s) \quad + \quad 2HCl(aq)$

$$\frac{M_{BaCl_2} \times V_{BaCl_2}}{M_{H_2SO_4} \times V_{H_2SO_4}} = \frac{1}{1}$$

3 $MnO_4^-(aq) \quad + \quad 5Fe^{2+}(aq) \quad + \quad 8H^+(aq) \quad \rightarrow \quad Mn^{2+}(aq) \quad + \quad 5Fe^{3+}(aq) \quad + \quad 4H_2O(l)$

$$\frac{M_{MnO_4^-} \times V_{MnO_4^-}}{M_{Fe^{2+}} \times V_{Fe^{2+}}} = \frac{1}{5}$$

Calculation examples

1 What is the molarity of a solution of NaOH which contains 4 g of NaOH in 250 cm^3 of solution?

M_r NaOH = 40 g mol^{-1}

4 g per 250 cm^3 = 16 g per 1000 cm^3

$$\therefore \text{ molarity} = \frac{16}{40} = \mathbf{0.040\ mol\ dm^{-3}}$$

This can also be written

$$\text{molarity} = \frac{(4 \times 1000) \times 1}{250 \times 40} = \mathbf{0.040\ mol\ dm^{-3}}$$

2 What mass of $KMnO_4$ would be needed to prepare 250 cm^3 of 0.020 mol dm^{-3} $KMnO_4$ solution? (M_r = 158)

1000 cm^3 of 0.020 mol dm^{-3} $KMnO_4$ will need 158 x 0.02 g

$$\therefore 250\ cm^3 \text{ will need } \frac{158 \times 0.02 \times 250}{1000} = \mathbf{0.79\ g}$$

3 How many moles of H_2SO_4 will be contained in 25 cm^3 of 0.10 mol dm^{-3} H_2SO_4?

$$\text{number of moles } \frac{0.10 \times 25}{1000} = \mathbf{0.0025\ moles}$$

4 25 cm^3 of 0.10mol dm^{-3} NaOH react with 50 cm^3 of a solution of H_2SO_4. What is the molarity of the H_2SO_4?

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

$$\frac{M_{NaOH} \times V_{NaOH}}{M_{H_2SO_4} \times V_{H_2SO_4}} = \frac{2}{1}$$

$$\therefore \quad \frac{0.1 \times 25}{M_{H_2SO_4} \times 50} = 2$$

$$\therefore \quad M_{H_2SO_4} = \frac{0.1 \times 25}{2 \times 50} = \mathbf{0.025\ mol\ dm^{-3}}$$

NB *If you are required to calculate the concentration in g dm^{-3} at this stage you need to multiply by the M_r of the material. In this case 98 g mol^{-1}*

5 What volume of 0.02 mol dm^{-3} $KMnO_4$ solution will be needed to react with 25 cm^3 of 0.1 mol dm^{-3} Iron(II) ammonium sulphate ?

NB in Iron(II) ammonium sulphate only the iron(II) ions react with the manganate(VII) ions

$$MnO^{4-}(aq) \quad + \quad 5Fe^{2+}(aq) \quad + \quad 8H^{+}(aq) \quad \rightarrow \quad Mn^{2+}(aq) \quad + \quad 5Fe^{3+}(aq) \quad + \quad 4H_2O(l)$$

$$\frac{M_{MnO_4^-} \times V_{MnO_4^-}}{M_{Fe^{2+}} \times V_{Fe^{2+}}} = \frac{1}{5}$$

$$\therefore \qquad \frac{0.02 \times V_{MnO_4^-}}{0.1 \times 25} = \frac{1}{5}$$

$$\therefore \qquad \mathbf{V_{MnO_4^-} = \frac{0.1 \times 25}{0.02 \times 5} = 25\,cm^3}$$

6 25 cm^3 of a solution of 0.05 mol dm^{-3} silver nitrate react with 10 cm^3 of a solution of NaCl. What is the concentration of NaCl in g dm^{-3} in the solution?

$$NaCl(aq) \quad + \quad AgNO_3(aq) \quad \rightarrow \quad NaNO_3(aq) \quad + \quad AgCl(s)$$

$$\frac{M_{NaCl} \times V_{NaCl}}{M_{AgNO_3} \times V_{AgNO_3}} = \frac{1}{1}$$

$$\therefore \qquad \frac{10 \times M_{NaCl}}{25 \times 0.05} = \frac{1}{1}$$

$$\therefore \qquad M_{NaCl} = \frac{25 \times 0.05}{10} = 0.125\,mol\,dm^{-3}$$

$$\therefore \qquad \textbf{concentration of NaCl} = \mathbf{0.125\,mol\,dm^{-3} \times 58.5 = 7.31\,g\,dm^{-3}}$$

7 In the reaction between an acid H_xA and 0.1 mol dm^{-3} NaOH solution. 25 cm^3 of a solution of 0.1 mol dm^{-3} H_xA react with 50 cm^3 of the 0.1 mol dm^{-3} NaOH. What is the value of x?

This is not as difficult as it looks. You need to think what the equation for the reaction would be.

$$H_xA(aq) + xNaOH(aq) \rightarrow Na_xA\ (aq) + xH_2O(l)$$

$$\therefore \quad \frac{M_{H_xA} \times V_{H_xA}}{M_{NaOH} \times V_{NaOH}} = \frac{1}{x}$$

$$\therefore \quad \frac{25 \times 0.1}{50 \times 0.1} = \frac{1}{x}$$

$$\therefore x = 2$$

Thus the acid is H_2A.

Method B

In this method the actual amounts of materials in the volumes involved are calculated rather than the ratios.

Example

25 cm^3 of 0.10 mol dm^{-3} NaOH react with 50 cm^3 of a solution of H_2SO_4.

What is the molarity of the H_2SO_4?

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

∴ 2 mol of NaOH react with 1 mol of H_2SO_4

In this case you know the concentration of the sodium hydroxide so

∴ 1 mol of NaOH reacts with 0.5 mol of H_2SO_4

always put the reactant you know as '1 mol'

In this reaction you have used 25 cm^3 of 0.10 mol dm^{-3} NaOH

$$= \frac{25 \times 0.10}{1000} \text{ mol of NaOH}$$

$$= 2.5 \times 10^{-3} \text{ mol}$$

This will react with 0.5 x 2.5 x 10^{-3} moles of H_2SO_4

= 1.25 x 10^{-3} moles of H_2SO_4

∴ 1.25 x 10^{-3} moles of H_2SO_4 will be found in 50 cm^3 of the solution

∴ In 1000 cm^3 of the acid the same solution there will be

$$= \frac{1000 \times (1.25 \times 10^{-3})}{50} \text{ moles of } H_2SO_4$$

= 0.0250 moles

∴ The concentration of the sulphuric acid is **0.025 mol dm^{-3}**.

Exercise 11a

Calculations based on concentrations in solution

Calculate the number of moles of the underlined species in the volume of solution stated.

1	25 cm^3 of 1.0 mol dm^{-3} <u>HCl</u>
2	50 cm^3 of 0.5 mol dm^{-3} <u>HCl</u>
3	250 cm^3 of 0.25 mol dm^{-3} <u>HCl</u>
4	500 cm^3 of 0.01 mol dm^{-3} <u>HCl</u>
5	25 cm^3 of 1.0 mol dm^{-3} <u>NaOH</u>
6	50 cm^3 of 0.5 mol dm^{-3} <u>KOH</u>
7	50 cm^3 of 0.25 mol dm^{-3} $\underline{HNO_3}$
8	100 cm^3 of 0.1 mol dm^{-3} $\underline{H_2SO_4}$
9	25 cm^3 of 0.05 mol dm^{-3} $\underline{KMnO_4}$
10	25 cm^3 of 0.2 mol dm^{-3} $\underline{FeSO_4}$

Calculate the mass of material in the given volume of solution

11	25 cm^3 of 1 mol dm^{-3} HCl
12	50 cm^3 of 0.5 mol dm^{-3} NaCl
13	100 cm^3 of 0.25 mol dm^{-3} NH_4NO_3
14	100 cm^3 of 0.1 mol dm^{-3} $AgNO_3$
15	25 cm^3 of 1 mol dm^{-3} $BaCl_2$
16	50 cm^3 of 0.2 mol dm^{-3} H_2SO_4
17	20 cm^3 of 0.1 mol dm^{-3} NaOH
18	50 cm^3 of 0.1 mol dm^{-3} K_2CrO_4
19	25 cm^3 of 0.02 mol dm^{-3} $KMnO_4$
20	25 cm^3 of 0.1 mol dm^{-3} $Pb(NO_3)_2$

What is the concentration in moles dm^{-3} of the following?

21 3.65 g of HCl in 1000 cm^3 of solution

22 3.65 g of HCl in 100 cm^3 of solution

23 6.62 g of $Pb(NO_3)_2$ in 250 cm^3 of solution

24 1.00 g of NaOH in 250 cm^3 of solution

25 1.96 g of H_2SO_4 in 250 cm^3 of solution

26 1.58 g of $KMnO_4$ in 250 cm^3 of solution

27 25.0 g of $Na_2S_2O_3.5H_2O$ in 250 cm^3 of solution

28 25.0 g of $CuSO_4.5H_2O$ in 250 cm^3 of solution

29 4.80 g of $(COOH)_2.2H_2O$ in 250 cm^3 of solution

30 10.0 g of $FeSO_4.(NH_4)_2SO_4.6H_2O$ in 250 cm^3 of solution

31 240 cm^3 of NH_3(g) dissolved in 1000 cm^3 of solution

32 480 cm^3 of HCl(g) dissolved in 100 cm^3 of solution

33 120 cm^3 of SO_2(g) dissolved in 250 cm^3 of solution

34 24 cm^3 of HCl(g) dissolved in 200 cm^3 of solution

35 100 cm^3 of NH_3(g) dissolved in 10 cm^3 of solution

Exercise 11b

Simple volumetric calculations

In this series of calculations you should start by writing the equation for the reaction taking place then generate the molarity/volume ratio. In some cases you will need to calculate the molarity of the solutions before you start the main part of the question.

For questions 1–10 calculate the molarity of the first named solution from the data below.

1	25 cm^3 of sodium hydroxide	reacts with	21.0 cm^3 of 0.2 mol dm^{-3} HCl
2	25 cm^3 of sodium hydroxide	reacts with	17.0 cm^3 of 0.1 mol dm^{-3} H_2SO_4
3	20 cm^3 of hydrochloric acid	reacts with	23.6 cm^3 of 0.1 mol dm^{-3} NaOH
4	20 cm^3 of hydrochloric acid	reacts with	20.0 cm^3 of a solution of NaOH containing 40 g dm^{-3} of NaOH
5	25 cm^3 of nitric acid	reacts with	15 cm^3 of a solution of 0.2 mol dm^{-3} NH_4OH
6	25 cm^3 of a solution of barium chloride	reacts with	20 cm^3 of a solution of 0.05 mol dm^{-3} sulphuric acid
7	25 cm^3 of a solution of NaCl	reacts with	10 cm^3 of a 0.02 mol dm^{-3} silver nitrate
8	10 cm^3 of a solution of $AlCl_3$	reacts with	30 cm^3 of 0.01 mol dm^{-3} silver nitrate
9	25 cm^3 of H_xA	reacts with	25 cm^3 of 0.2 mol dm^{-3} NaOH to give Na_2A
10	25 cm^3 of H_3PO_4	reacts with	100 cm^3 of 0.1 mol dm^{-3} NaOH to give NaH_2PO_4

11	25 cm^3 of a solution of 0.1 mol dm^{-3} NaOH reacts with 50 cm^3 of a solution of hydrochloric acid. What is the molarity of the acid?
12	25 cm^3 of a solution of 0.2 mol dm^{-3} KOH reacts with 30 cm^3 of a solution of nitric acid. What is the concentration of the acid in moles dm^{-3}?
13	In a titration 25 cm^3 of ammonia solution react with 33.30 cm^3 of 0.1 mol dm^{-3} HCl. What is the concentration of the ammonia solution in g dm^{-3}?
14	In the reaction between iron(II) ammonium sulphate and potassium manganate(VII) solution. 25 cm^3 of the Fe^{2+} solution reacted with 24.8 cm^3 of 0.020 mol dm^{-3} $KMnO_4$ solution. What is the molarity of the iron(II) ammonium sulphate solution?
15	10 cm^3 of a solution of NaCl react with 15 cm^3 of 0.02 mol dm^{-3} silver nitrate solution. What is the concentration of the NaCl solution in g dm^{-3}?
16	25 cm^3 of a solution of an acid H_xA containing 0.1 mol dm^{-3} of the acid in each 1000 cm^3 of solution reacts with 75 cm^3 of a solution of 0.1 mol dm^{-3} NaOH. What is the value of x?
17	25 cm^3 of a solution of sodium carbonate react with 10 cm^3 of a 0.1 mol dm^{-3} HCl. What is the concentration of the sodium carbonate?
18	What volume of 0.1 mol dm^{-3} HCl will be needed to react with 25 cm^3 of 0.2 mol dm^{-3} NaOH?
19	What volume of 0.05 mol dm^{-3} H_2SO_4 will be needed to react with 25 cm^3 of 0.2 mol dm^{-3} NaOH?
20	What volume of 0.02 mol dm^{-3} $KMnO_4$ will be needed to react with 25 cm^3 of 0.1 mol dm^{-3} $FeSO_4$ solution?

The last five questions will require you to use the skills you have learnt in this section, together with those from other sections.

21 What weight of silver chloride will be produced if 25 cm^3 of 0.1 mol dm^{-3} silver nitrate is added to excess sodium chloride solution?

22 What weight of calcium carbonate will dissolve in 100 cm^3 of 0.2 mol dm^{-3} HCl?

23 What volume of carbon dioxide will be produced if 100 cm^3 of 0.2 mol dm^{-3} HNO_3 is added to excess sodium carbonate solution?

24 What weight of magnesium will dissolve in 10 cm^3 of 1 mol dm^{-3} HCl and what volume of hydrogen will be produced?

25 What volume of ammonia gas will be produced in the following reaction if 50 cm^3 of 0.5 mol dm^{-3} sodium hydroxide is boiled with 50 cm^3 of 0.4 mol dm^{-3} ammonium chloride solution? (Care: one of these is in excess.)

$$NaOH(aq) + NH_4Cl(aq) \rightarrow NaCl(aq) + H_2O(l) + NH_3(g)$$

Section 12

Data — The periodic table

THE PERIODIC TABLE

key

Atomic Number
Symbol
Name
Molar mass in g mol^{-1}

Group

Period	1	2											3	4	5	6	7	8
1	1 H Hydrogen 1																	2 He Helium 4
2	3 Li Lithium 7	4 Be Berylium 9											5 B Boron 11	6 C Carbon 12	7 N Nitrogen 14	8 O Oxygen 16	9 F Fluorine 19	10 Ne Neon 20
3	11 Na Sodium 23	12 Mg Magnesium 24											13 Al Aluminium 27	14 Si Silicon 28	15 P Phosphorus 31	16 S Sulphur 32	17 Cl Chlorine 35.5	18 Ar Argon 40
4	19 K Potassium 39	20 Ca Calcium 40	21 Sc Scandium 45	22 Ti Titanium 48	23 V Vanadium 51	24 Cr Chromium 52	25 Mn Manganese 55	26 Fe Iron 56	27 Co Cobalt 59	28 Ni Nickel 59	29 Cu Copper 63.5	30 Zn Zinc 65.4	31 Ga Gallium 70	32 Ge Germanium 73	33 As Arsenic 75	34 Se Selenium 79	35 Br Bromine 80	36 Kr Krypton 84
5	37 Rb Rubidium 85	38 Sr Strontium 88	39 Y Yttrium 89	40 Zr Zirconium 91	41 Nb Niobium 93	42 Mo Molybdenum 96	43 Tc Technetium (99)	44 Ru Ruthenium 101	45 Rh Rhodium 103	46 Pd Palladium 106	47 Ag Silver 108	48 Cd Cadmium 112	49 In Indium 115	50 Sn Tin 119	51 Sb Antimony 122	52 Te Tellurium 128	53 I Iodine 127	54 Xe Xenon 131
6	55 Cs Caesium 133	56 Ba Barium 137	57 La ▲ Lanthanum 139	72 Hf Hafnium 178	73 Ta Tantalum 181	74 W Tungsten 184	75 Re Rhenium 186	76 Os Osmium 190	77 Ir Iridium 192	78 Pt Platinum 195	79 Au Gold 197	80 Hg Mercury 201	81 Tl Thallium 204	82 Pb Lead 207	83 Bi Bismuth 209	84 Po Polonium (210)	85 At Astatine (210)	86 Rn Radon (222)
7	87 Fr Francium (223)	88 Ra Radium (226)	89 Ac ▲▲ Actinium (227)	104 Unq Unnilquadium (261)	105 Unp Unnilpentium (262)	106 Unh Unnilhexium (263)												

58 Ce Cerium 140	59 Pr Praseo-dymium 141	60 Nd Neodymium 144	61 Pm Promethium (147)	62 Sm Samarium 150	63 Eu Europium 152	64 Gd Gadolinium 157	65 Tb Terbium 159	66 Dy Dysprosium 163	67 Ho Holmium 165	68 Er Erbium 167	69 Tm Thulium 169	70 Yb Ytterbium 173	71 Lu Lutetium 175
90 Th Thorium 232	91 Pa Protactinium (231)	92 U Uranium 238	93 Np Neptunium (237)	94 Pu Plutonium (242)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (245)	98 Cf Californium (251)	99 Es Einsteinium (254)	100 Fm Fermium (253)	101 Md Mendelevium (256)	102 No Nobelium (254)	103 Lr Lawrencium (257)

Answers

Exercise 1

1	18	**21**	11	**41**	159.5
2	44	**22**	164	**42**	161.4
3	17	**23**	74	**43**	170
4	46	**24**	136	**44**	53.5
5	28	**25**	208	**45**	132
6	64	**26**	1335	**46**	117.0
7	80	**27**	213	**47**	122.5
8	81	**28**	342	**48**	166.0
9	98	**29**	152	**49**	74.5
10	63	**30**	127	**50**	69.0
11	58.5	**31**	162.5	**51**	249.5
12	85	**32**	400	**52**	278
13	106	**33**	223	**53**	964
14	40	**34**	239	**54**	248
15	142	**35**	685	**55**	126
16	158	**36**	331	**56**	246
17	194	**37**	278	**57**	2635
18	100	**38**	303	**58**	60
19	166	**39**	99.0	**59**	58
20	195	**40**	134.5	**60**	122

Exercise 2

1 NaCl	**21** $BaSO_4$	**41** $PbCO_3$	**61** PCl_3
2 NaOH	**22** $AlCl_3$	**42** PbO	**62** PCl_5
3 Na_2CO_3	**23** Al_2O_3	**43** PbO_2	**63** P_2O_3
4 Na_2SO_4	**24** $Al(OH)_3$	**44** $PbCl_2$	**64** P_2O_5
5 NO_3PO_4	**25** $Al_2(SO_4)_3$	**45** $PbCl_4$	**65** H_3PO_4
6 KCl	**26** $CuSO_4$	**46** PbS	**66** H_2SO_4
7 KBr	**27** CuO	**47** $SnCl_2$	**67** HNO_3
8 KI	**28** $CuCl_2$	**48** $SnCl_4$	**68** HCl
9 $KHCO_3$	**29** $Cu(NO_3)_2$	**49** $FeSO_4$	**69** CCl_4
10 KNO_2	**30** Cu_2O	**50** $FeCl_2$	**70** $SiCl_4$
11 $MgCl_2$	**31** CuCl	**51** $Fe_2(SO_4)_3$	**71** SiO_2
12 $Mg(NO_3)_2$	**32** $Zn(NO_3)_2$	**52** $FeCl_3$	**72** SO_2
13 $Mg(OH)_2$	**33** $ZnCO_3$	**53** $Fe(OH)_3$	**73** SO_3
14 MgO	**34** ZnO	**54** $Fe(OH)_2$	**74** H_2S
15 $MgCO_3$	**35** AgCl	**55** NH_4Cl	**75** Cl_2O
16 CaO	**36** AgBr	**56** $(NH_4)_2CO_3$	**76** NO_2
17 $CaCl_2$	**37** AgI	**57** NH_4OH	**77** NO
18 $CaSO_4$	**38** $AgNO_3$	**58** NH_4NO_3	**78** CO_2
19 $CaCO_3$	**39** Ag_2O	**59** $(NH_4)_2SO_4$	**79** CO
20 $BaCl_2$	**40** $Pb(NO_3)_2$	**60** $(NH_4)_3PO_4$	**80** HOH/H_2O

Exercise 3

1 Water
2 Carbon dioxide
3 Ammonia
4 Oxygen
5 Hydrogen
6 Sulphur dioxide (or IV oxide)
7 Sulphur trioxide (or VI oxide)
8 Hydrogen chloride
9 Hydrogen iodide
10 Hydrogen fluoride
11 Methane
12 Hydrogen sulphide
13 Hydrogen bromide
14 Sulphuric acid
15 Nitric acid
16 Sodium chloride
17 Sodium nitrate
18 Sodium carbonate
19 Sodium hydroxide
20 Sodium sulphate
21 Calcium chloride
22 Calcium nitrate
23 Calcium hydroxide
24 Calcium sulphate
25 Barium chloride
26 Aluminium chloride
27 Aluminium nitrate
28 Aluminium sulphate
29 Iron(II) sulphate
30 Iron(II)chloride
31 Iron(III) chloride
32 Iron(III) sulphate
33 Lead(II) oxide
34 Lead(IV) oxide
35 Lead(II) nitrate
36 Lead(II) chloride
37 Lead (II) sulphate
38 Copper(II) nitrate
39 Copper(I) chloride
40 Copper(II) chloride
41 Copper(II) sulphate
42 Zinc chloride
43 Silver nitrate
44 Ammonium chloride
45 Ammonium sulphate
46 Ammonium vanadate(V)
47 Potassium chlorate(V)
48 Potassium iodate
49 Sodium chlorate(I)
50 Sodium nitrite
51 Ethane
52 Butane
53 Octane
54 Ammonium carbonate
55 Potassium manganate(VII)
56 Potassium chromate(VI)
57 Potassium hydrogencarbonate
58 Potassium iodide
59 Cobalt(II) nitrate
60 Potassium astatide

Exercise 4a

1	0.50	**26**	0.10
2	2.0	**27**	0.10
3	0.10	**28**	0.0085
4	5.0	**29**	0.26
5	20	**30**	0.104
6	0.010	**31**	0.20
7	1.0	**32**	0.082
8	0.22	**33**	0.050
9	0.0010	**34**	1.34
10	0.050	**35**	0.025
11	0.33	**36**	0.204
12	0.25	**37**	0.071
13	0.021	**38**	0.010
14	0.020	**39**	0.050
15	0.125	**40**	0.254
16	0.020	**41**	0.0125
17	0.167	**42**	0.152
18	1.0	**43**	0.10
19	0.046	**44**	0.053
20	0.020	**45**	0.0043
21	0.0010	**46**	0.036
22	0.25	**47**	0.266
23	0.02	**48**	0.024
24	0.0025	**49**	0.025
25	0.20	**50**	1.574

Exercise 4b

1 36 g
2 132 g
3 47.6 g
4 23 g
5 33.6 g
6 40.96 g
7 240 g
8 81 g
9 1.152 g
10 9.45 g
11 26.3 g
12 59.5 g
13 11.66 g
14 80.0 g
15 127.8 g
16 7.9 g
17 34.92 g
18 90 g
19 249 g
20 23.4 g
21 12.2 g
22 672.4 g
23 0.296 g
24 13.6 g
25 43.68 g
26 14.95 g
27 76.2 g
28 10.03 g
29 17.82 g
30 145.2 g
31 2.925 g
32 12.25 g
33 21.4 g
34 745 g
35 0.069 g
36 49.9 g
37 27.8 g
38 4.82 g
39 9.92 g
40 302.4 g
41 756.5 g
42 39.53 g
43 10.2 g
44 11.6 g
45 9.76 g
46 4.34 g
47 9.59 g
48 41.0 g
49 304 g
50 1397 g

Exercise 4c

1 24000 cm^3
2 2400 cm^3
3 12000 cm^3
4 48000 cm^3
5 2880 cm^3
6 81600 cm^3
7 2640 cm^3
8 96 cm^3
9 240000 cm^3
10 10800 cm^3
11 134.4 cm^3
12 216 cm^3
13 960 cm^3
14 2952 cm^3
15 55.2 cm^3
16 192000 cm^3
17 0.24 cm^3
18 144000 cm^3
19 182.4 cm^3
20 72000 cm^3

Exercise 4d

1	0.0083 mol	**11**	0.0292 mol
2	0.0208 mol	**12**	0.2333 mol
3	0.0416 mol	**13**	0.0917 mol
4	0.0533 mol	**14**	0.0088 mol
5	0.0098 mol	**15**	0.0333 mol
6	0.0094 mol	**16**	0.0033 mol
7	0.0106 mol	**17**	0.000080 mol
8	0.0033 mol	**18**	0.8333 mol
9	0.0833 mol	**19**	0.0175 mol
10	0.10 mol	**20**	0.0375 mol

Exercise 4e

1	0.367 g	**11**	0.875 g
2	0.354 g	**12**	10.27 g
3	1.166 g	**13**	2.38 g
4	5.333 g	**14**	0.263 g
5	0.78 g	**15**	1.217 g
6	0.763 g	**16**	0.270 g
7	0.757 g	**17**	0.011 g
8	0.233 g	**18**	38.33 g
9	0.167 g	**19**	0.683 g
10	3.20 g	**20**	1.05 g

Exercise 4f

1	1091 cm^3	**11**	56000 cm^3
2	7059 cm^3	**12**	30545 cm^3
3	8571 cm^3	**13**	20308 cm^3
4	7500 cm^3	**14**	16000 cm^3
5	702 cm^3	**15**	5260 cm^3
6	670 cm^3	**16**	2370 cm^3
7	3380 cm^3	**17**	375 cm^3
8	30000 cm^3	**18**	12000 cm^3
9	2400000 cm^3	**19**	26526 cm^3
10	180000 cm^3	**20**	77143 cm^3

Exercise 4g

1 160
2 64
3 80
4 71
5 2.0
6 28
7 30
8 58
9 32
10 28
11 34
12 17
13 38
14 28
15 44
16 32
17 211
18 36.5
19 81
20 128

Exercise 5

Section (a)

1 $CaCO_3$
2 Na_2SO_4
3 $Na_2S_2O_3$
4 PbO
5 Pb_3O_4
6 H_3PO_3
7 H_2SO_3
8 CH_4
9 C_3H_8
10 HO (giving H_2O_2)
11 $H_4N_2O_3$ (NH_4NO_3)
12 $FeSO_{11}H_{14}$ ($FeSO_4$ - $7H_2O$)

Section (b)

1 C_2H_4
2 C_3H_6
3 P_2I_4
4 $N_2H_4S_2O_8$
5 P_4O_{10}
6 $C_2H_4O_2$ - CH_3COOH
7 C_4H_{10}
8 Fe_2O_3
9 $H_2S_2O_8$
10 C_6H_6

Section (c)

1 PbO
2 KO_2
3 C_2H_2
4 $AlCl_3$
5 CH_4
6 yes
7 $CuSO_4$ $5H_2O$
8 PCl_5, PCl_3, Cl_2

Exercise 6a

1	$2H_2$	+	O_2	$\rightarrow$	$2H_2O$				
2	$BaCl_2$	+	$2NaOH$	$\rightarrow$	$Ba(OH)_2$	+	$2NaCl$		
3	H_2SO_4	+	$2KOH$	$\rightarrow$	K_2SO_4	+	$2H_2O$		
4	K_2CO_3	+	$2HCl$	$\rightarrow$	$2KCl$	+	H_2O	+	CO_2
5	$CaCO_3$	+	$2HNO_3$	$\rightarrow$	$Ca(NO_3)_2$	+	H_2O	+	CO_2
6	Ca	+	$2H_2O$	$\rightarrow$	$Ca(OH)_2$	+	H_2		
7	$Pb(NO_3)_2$	+	$2NaI$	$\rightarrow$	PbI_2	+	$2NaNO_3$		
8	$Al_2(SO_4)_3$	+	$6NaOH$	$\rightarrow$	$2Al(OH)_3$	+	$3Na_2SO_4$		
9	$Al(OH)_3$	+	$NaOH$	$\rightarrow$	$NaAlO_2$	+	$2H_2O$		
10	$2Pb(NO_3)_2$	$\rightarrow$	$2PbO$	+	$4NO_2$		O_2		
11	$2FeSO_4$	$\rightarrow$	Fe_2O_3	+	SO_2		SO_3		
12	NH_4NO_3	$\rightarrow$	N_2O	+	$2H_2O$				
13	$2NaNO_3$	$\rightarrow$	$2NaNO_2$	+	O_2				
14	CH_4	+	$2O_2$	$\rightarrow$	CO_2	+	$2H_2O$		
15	$2C_4H_{10}$	+	$13O_2$	$\rightarrow$	$8CO_2$	+	$10H_2O$		
16	PCl_3	+	$3H_2O$	$\rightarrow$	H_3PO_3	+	$3HCl$		
17	$8HNO_3$	+	$3Cu$	$\rightarrow$	$3Cu(NO_3)_2$	+	$3NO$	+	$4H_2O$
18	$4HNO_3$	+	Cu	$\rightarrow$	$Cu(NO_3)_2$	+	$2NO_2$	+	$2H_2O$
19	H_3PO_4	+	$NaOH$	$\rightarrow$	NaH_2PO_4	+	H_2O		
20	H_3PO_4	+	$3NaOH$	$\rightarrow$	Na_3PO_4	+	$3H_2O$		
21	H_3PO_4	+	$2NaOH$	$\rightarrow$	Na_2HPO_4	+	$2H_2O$		
22	$6NaOH$	+	$3Cl_2$	$\rightarrow$	$NaClO_3$	+	$5NaCl$	+	$3H_2O$
23	N_2	+	$3H_2$	$\rightarrow$	$2NH_3$				
24	$2NaBr$	+	H_2SO_4	$\rightarrow$	Na_2SO_4	+	HBr		
25	$2HBr$	+	H_2SO_4	$\rightarrow$	$2H_2O$	+	SO_2	+	Br_2
26	$3C_2H_5OH$	+	PCl_3	$\rightarrow$	$3C_2H_5Cl$	+	H_3PO_3		
27	Fe_3O_4	+	$4H_2$	$\rightarrow$	$3Fe$	+	$4H_2O$		

28	Fe_2O_3	+	$3CO$	→	$2Fe$	+	$3CO_2$			
29	C_2H_5OH	+	CH_3CO_2H	→	$CH_3CO_2C_2H_5$	+	H_2O			
30	$2KMnO_4$	+	$16HCl$	→	$2KCl$	+	$2MnCl_2$	+ $8H_2O$	+	$5\ Cl_2$

Exercise 6b

1 Hydrogen is not H but H_2, which gives

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

2 Since the valency of lead is 2 not 1 lead nitrate is not $PbNO_3$ but $Pb(NO_3)_2$ and also lead chloride is $PbCl_2$

$$Pb(NO_3)_2(aq) + 2NaCl(aq) \rightarrow PbCl_2(s) + 2NaNO_3(aq)$$

3 Calcium hydroxide is $Ca(OH)_2$

$$Ca(OH)_2(aq) + 2HCl(aq) \rightarrow CaCl_2(aq) + 2H_2O(l)$$

4 This does not balance.

$$C_2H_4(g) + 3O_2(g) \rightarrow 2CO_2(g) + H_2O(l)$$

5 A magnesium compound cannot give a calcium compound!

6 Ozone O_3 is not produced by heating a nitrate O_2 is.

$$2Cu(NO_3)_2(s) \rightarrow 2CuO(s) + 4NO_2(g) + O_2(g)$$

7 This reaction does not take place and so no equation can be written.

8 Aluminium has a valency of 3 not 2 as in this equation.

$$AlCl_3(s) + 3KOH(aq) \rightarrow Al(OH)_3(s) + 3KCl(aq)$$

9 Sodium has a valency of 1 not 2 as in this equation

$$Na_2CO_3(s) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2O(l) + CO_2(g)$$

10 Silver chloride is not soluble in water. Thus the AgCl needs a (s) symbol

Exercise 6c

1	$Zn(s)$	+	$CuSO_4(aq)$	$\rightarrow$	$Cu(s)$	+	$ZnSO_4(aq)$			
2	$Ca(OH)_2(s)$	+	$2NH_4Cl(s)$	$\rightarrow$	$CaCl_2(s)$	+	$H_2O(g)$	+	$NH_3(g)$	
3	$2Pb(NO_3)_2(s)$	$\rightarrow$	$2PbO(s)$	+	$4NO_2(g)$	+	$O_2(g)$			
4	$SiCl_4(l)$	+	$2H_2O(l)$	$\rightarrow$	$SiO_2(s)$	+	$HCl(g)$			
5	$Ca(HCO_3)_2(aq)$	$\rightarrow$	$CaCO_3(s)$	+	$H_2O(l)$	+	$CO_2(g)$			
6	$2C_8H_{18}(g)$	+	$25O_2(g)$	$\rightarrow$	$16CO_2(g)$	+	$8H_2O(l)$			
7	$6NaOH(aq)$	+	$3Cl_2(g)$	$\rightarrow$	$NaClO_3(aq)$	+	$5NaCl(aq)$	+	$3H_2O(l)$	
	$6NaOH(aq)$	+	$3Br_2(g)$	$\rightarrow$	$NaBrO_3(aq)$	+	$5NaBr(aq)$	+	$3H_2O(l)$	
	$6NaOH(aq)$	+	$3I_2(g)$	$\rightarrow$	$NaIO_3(aq)$	+	$5NaI(aq)$	+	$3H_2O(l)$	
8	$2M(s)$	+	$2H_2O(l)$	$\rightarrow$	$2MOH(aq)$	+	$H_2(g)$			
					Where M = Li, Na, K, Rb or Cs					
9	$SnCl_2(aq)$	+	$2HgCl_2(aq)$	$\rightarrow$	$2HgCl\ (s)$	+	$SnCl_4(aq)$			

10 $9H_2SO_4 + 8KI \rightarrow 4I_2 + H_2S + 8KHSO_4 + 4H_2O$

Exercise 7

1	$AlCl_3$	+	$3AgNO_3$	→	$Al(NO_3)_3$	+	$3AgCl$	
2	K_2CrO_4	+	$Pb(NO_3)_2$	→	$PbCrO_4$	+	$2KNO_3$	
3	$2AgNO_3$	→	$2Ag$	+	$2NO_2$	+	O_2	

4 i) 1 mole

ii) 2 moles

iii)

H_3PO_4	+	$NaOH$	→	NaH_2PO_4	+	H_2O
H_3PO_4	+	$2NaOH$	→	Na_2HPO_4	+	$2H_2O$

iv) 75 cm^3

5 x = 3

6 x = 5

$CuSO_4.5H_2O \rightarrow CuSO_4 + 5H_2O$

7	$4NH_3$	+	$5O_2$	→	$4NO$	+	$6H_2O$
8	C_3H_8	+	$5O_2$	→	$3CO_2$	+	$4H_2O$

9 It is

10 $FeSO_4.7H_2O \rightarrow Fe_2O_3 + SO_2 + SO_3 + 14H_2O$

Exercise 8

1 11.2 g

2 21.6 g

3 0.682 g of ethanoic acid and 0.523 g of ethanol

4 143 tonnes

5 14.5 g

6 8.0 g of sodium hydroxide, 9.75 g of copper hydroxide

7 12000 cm^3

8 54. 7 g of calcium nitrate, 8.0 dm^3 of carbon dioxide

9 6 dm^3 total (4.8 dm^3 of nitrogen dioxide and 1.2 dm^3 of oxygen)

10 $Mg + H_2SO_4 + 7H_2O \rightarrow Mg\ SO_4.7H_2O + H_2$
41.0 g

11 31.9 g

12 324.3 g

13 5.11 g of ethanol, 2.67 dm^3 of carbon dioxide

14 (i) 12.30 g of zinc hydroxide
(ii) 9.12 g of aluminium hydroxide
(iii) 9.67 g of magnesium hydroxide

15 0.600 dm^3

16 0.100 g

17 2.94 g of sodium chloride, 1.065 g of sodium chlorate(v)

18 4.15 x 10^6 dm^3 of nitrogen, 12.5 x 10^6 dm^3 of hydrogen

19 63 tonnes of nitric acid, 4.8 x 10^7 dm^3 of oxygen

20 2198 g of calcium carbonate, 4.395 dm^3 of 10M HCl

Exercise 9

Section (a)

1	20cm^3 O_2	10cm^3 CO_2	20cm^3 H_2O (g)
2	30cm^3 O_2	20cm^3 CO_2	20cm^3 H_2O (g)
3	25cm^3 O_2	20cm^3 CO_2	10cm^3 H_2O (g)
4	125cm^3 O_2	80cm^3 CO_2	90cm^3 H_2O (g)
5	30cm^3 H_2	20cm^3 NH_3	

Section (b)

1 500cm^3 O_2 ($2NO + O_2 \rightarrow 2NO_2$)

2 375cm^3 air ($2SO_2 + O_2 \rightarrow 2SO_3$)

3 2500cm^3 NH_3 needed $\quad ^5/_4$ x 2500 = 3125cm^3 $O_2 \rightarrow$ 15625cm^3 air

4 6.5 x 24000cm^3 = 156m^3

5 24000cm^3

6 Final volume = 20cm^3 (10cm^3 CO_2 + 10 cm^3 unused O_2)

7 Final volume = 77.5cm^3 (40cm^3 CO_2 + 37.5cm^3 used O_2)

8 This time the CH_4 is in excess. We must assume that CO_2 is produced (not CO or C)!

Final volume = 60 cm^3 (30 cm^3 CO_2 + 30 cm^3 CH_4)

9

N_2 +	$3H_2$	$\rightarrow$	$2NH_3$
10 cm^3	30 cm^3		20 cm^3
		+	30 cm^{3}excess

20 cm^3 NH_3 produced + 30 cm^3 excess H_2

10

2 H_2	+	O_2	$\rightarrow$	$2H_2O$
10 cm^3		5 cm^3		
	+	5 cm^3 excess		

Final volume = 5 cm^3 (all excess O_2)

Exercise 10

1 $Pb^{2+}(aq) + 2OH^-(aq) \rightarrow Pb(OH)_2(s)$

2 $Al^{3+}(aq) + 3OH^-(aq) \rightarrow Al(OH)_3(s)$

3 $Al(OH)_3(s) + OH^-(aq) \rightarrow AlO_2^-(aq) + 2H_2O(l)$

4 $Cl_2(g) + 6OH^-(aq) \rightarrow ClO_3^-(aq) + 5Cl^-(aq) + 3H_2O(l)$

5 $2S_2O_3^{2-}(aq) + I_2(s) \rightarrow S_4O_6^{2-}(aq) + 2I^-(aq)$

6 $Cu^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(OH)_2(s)$

7 $CO_3^{2-}(s) + 2H^+(aq) \rightarrow H_2O(l) + CO_2(g)$

8 $Zn(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g)$

9 $Zn(s) + Pb^{2+}(aq) \rightarrow Pb(s) + Zn^{2+}(aq)$

10 $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

11 $Mg(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$

12 $CO_3^{2-}(s) + 2H^+(aq) \rightarrow H_2O(l) + CO_2(g)$

13 $CuO(s) + 2H^+(aq) \rightarrow Cu^{2+}(aq) + H_2O(l)$

14 $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$

15 $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$

16 $Zn(s) + 2Ag^+(aq) \rightarrow Zn^{2+}(aq) + 2Ag(s)$

17–20 $20H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

In every case the reaction is the same

Exercise 11a

1 0.025 moles
2 0.025 moles
3 0.0625
4 0.005 moles
5 0.025 moles
6 0.025 moles
7 0.0125moles
8 0.01 moles
9 0.00125 moles
10 0.005 moles
11 0.9125 g
12 1.463 g
13 2 g
14 1.70 g
15 5.2 g
16 0.98 g
17 0.08 g
18 0.97 g
19 0.079 g
20 0.828 g
21 0.1 mol dm^{-3}
22 1.0 mol dm^{-3}
23 0.03 mol dm^{-3}
24 0.1 mol dm^{-3}
25 0.03 mol dm^{-3}
26 0.04 mol dm^{-3}
27 0.40 mol dm^{-3}
28 0.40 mol dm^{-3}
29 0.152 mol dm^{-3}
30 0.0102 mol dm^{-3}
31 0.01 mol dm^{-3}
32 0.2 mol dm^{-3}
33 0.02 mol dm^{-3}
34 0.005 mol dm^{-3}
35 0.417 mol dm^{-3}

Exercise 11b

1 0.168 mol dm^{-3}
2 0.136 mol dm^{-3}
3 0.118 mol dm^{-3}
4 1.0 mol dm^{-3}
5 0.12 mol dm^{-3}
6 0.040 mol dm^{-3}
7 0.0080 mol dm^{-3}
8 0.010 mol dm^{-3}
9 0.10 mol dm^{-3}
10 0.40 mol dm^{-3}
11 0.050 mol dm^{-3}
12 0.167 mol dm^{-3}
13 2.26 g dm^{-3}
14 0.099 mol dm^{-3}
15 1.755 g dm^{-3}
16 3.0
17 0.02 mol dm^{-3}
18 50 cm^3
19 50 cm^3
20 25 cm^3
21 0.359 g
22 1.0 g
23 240 cm^3
24 0.12 g Mg
120 cm^3 H_2
25 480 cm^3

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