GCE

Chemistry

Student workbook

Edexcel Advanced Subsidiary GCE in Chemistry (8CH01)

Edexcel Advanced GCE in Chemistry (9CH01)

Moles, Formulae and Equations

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Contents

Introduction

This workbook, developed from an earlier version, offers support to students in transition from GCSE Additional Science or GCSE Chemistry and the Advanced Subsidiary GCE.

The workbook aims to help students practise their skills in the areas of formulae, equations and simple mole equations. It gives examples for them to work through to help build their confidence. Some sections involve multi-step calculations.

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Section 1: Atoms

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

We now know that atoms can be split and that there are particles smaller than atoms, sub-atomic particles, electrons, protons and neutrons. You will need to know 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 6×10^{23} atoms. It is very difficult to ‘see’ an individual atom and 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. Li, O, Cl, C are all formulae which represent atoms. Some but not all of these can exist on their own. Oxygen, for example, unless combined with something else always exists as oxygen *molecules*, O_2, which contain two atoms. 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 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 will need 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 goalposts. Between the electron and the nucleus is empty space.

Atoms are the particles whose symbols are found in the periodic table of elements given in all your examination papers and also in *Section 12* of this workbook. You can see that 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 a helium atom and so on.

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

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

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

The definition of ***Relative Atomic Mass*** $\mathbf{A_r}$ as follows.

> **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 **R*elative 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.**

The relative molecular mass of a molecule is calculated by adding together the relative atomic masses of the atoms in the chemical formulae.

Definition of **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: that relative atomic mass, molecular mass and formula mass have no units.

Examples: Calculation of Molar Mass from relative atomic mass data

Before you start these questions make sure you read *Section 4*: *The mole* of this workbook.

When you carry out experiments you will weigh chemicals in grams. Molar Mass has the same numerical value as *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 sulfuric 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 **sulfur** of mass 32.1	= 1 x 32.1	= 32.1 g mol^{-1}
4 atoms of **oxygen** of mass 16	= 4 x 16	= 64 g mol^{-1}
	Total mass	**= 98.1 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 h**ead** of mass 207.2	= 1 x 207.2	= 207.2 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	**= 331.2 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 sulfate. 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 **sulfur** of mass 32.1	= 1 x 32.1	= 32.1 g mol^{-1}
	4 atoms of **oxygen** each of mass 16	= 4 x 16	= 64 g mol^{-1}
In $5H_2O$	5 x 2 atoms of **hydrogen** each of mass 1	= 10 x 1	= 10 g mol^{-1}
	5 x 1 atoms of **oxygen** each of mass 16	= 5 x 16	= 80 g mol^{-1}
		Total mass	**= 249.6 g mol^{-1}**

Calculations of this type are generally written as follows

$CuSO_4.5H_2O$ = [63.5 + 32.1 + (4 x 16) + 5{(2 x 1) + 16}] = 249.6 g mol^{-1}

Exercise 1: Calculation of the Molar Mass of compounds

Calculate the Molar Mass of the following compounds. You will find data concerning relative atomic masses on the periodic table of elements (in *Section 12*). When you have finished this set of calculations keep the answers for reference. You will find them useful for 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 contain, eg $FeSO_4$ contains iron, sulfur and oxygen
- how many atoms of each kind are in each molecule, eg H_2SO_4 contains two atoms of hydrogen, one atom of sulfur 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 2g 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 a large number of chemical formulae by heart. However, it is useful to know a few of them and then be able to work out the rest.

You can work out the formulae of compounds containing metals from the charges on the ions.

- Metals in group 1 always have charge +1 in their compounds.
- Metals in group 2 always have charge +2 in their compounds.
- Metals in group 3 always have charge +3 in their compounds.
- Ions of group 7 elements have charge −1.
- Ions of group 6 elements have charge −2.
- Ions of group 5 elements have charge −3.

In the compound, the number of positive and negative charges is equal so that the overall charge is zero.

Some metals form more than one ion, and this is shown by a roman numeral in the name. Iron(II) chloride contains Fe^{2+} ions so the compound is $FeCl_2$. Iron(iii) chloride contains Fe^{3+} ions so the compound is $FeCl_3$.

Some ions have formulae which you cannot deduce from the periodic table, and you will need to learn these:

- OH^- hydroxide
- NO_3^- nitrate
- CO_3^{2-} carbonate
- SO_4^{2-} sulfate
- NH_4^+ ammonium.

Compounds which do not contain metals have covalent bonds. The number of bonds a non-metal can form depends on the number of electrons in its outer shell.

As a rule:

- carbon forms 4 bonds
- nitrogen forms 3 bonds
- phosphorus can form 3 or 5 bonds
- oxygen and sulfur form 2 bonds
- halogens form 1 bond.

Here are a few examples.

- **Sodium sulfate**

  The formula of a sodium ion is Na^+

  The formula of a sulfate ion is SO_4^{2-}

  There must be two sodium ions, each with charge 1+, to balance the two – charges on sulfate.

  The formula with two Na^+ and one SO_4^{2-} is written Na_2SO_4

- **Calcium hydrogen carbonate**

  The formula of a calcium ion is Ca^{2+}

  The formula of a hydrogen carbonate ion is HCO_3^-

  There must be two hydrogen carbonate ions, each with charge 1−, to balance the two + charges on calcium.

  The formula with one Ca^{2+} and two HCO_3^- is written $Ca(HCO_3)_2$

Note: A bracket *must* be placed around a group or ion if it is multiplied by 2 or more *and/or* composed of more than one element. For example,

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

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

  $Ca_2(CO_3)_2 = CaCO_3$

  However, you should **not** do this for organic compounds. For example, C_2H_4 has 2 atoms of carbon and four of hydrogen so it cannot be cancelled down to CH_2.

- Copper(I) oxide means use copper with charge 1, ie Cu_2O. Lead(II) nitrate means use lead with charge 2, ie $Pb(NO_3)_2$.

The periodic table can help you find the charge on an element and the number of bonds it can make, and hence the formula of its compounds.

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

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

Symbols and charges of common elements and ions

Elements	Symbol	Charge on ion	Ions	Symbol	Charge on ion
Aluminium	Al	+3	Ammonium	NH_4	+1
Barium	Ba	+2	Carbonate	CO_3	−2
Bromine	Br	−1	Hydrogen-carbonate	HCO_3	−1
Calcium	Ca	+2	Hydrogen-sulfate	HSO_3	−1
Chlorine	Cl	−1	Hydroxide	OH	−1
Cobalt	Co	+2	Nitrate	NO_3	−1
Copper	Cu	+1 and 2	Nitrite	NO_2	−1
Hydrogen	H	+1	Sulfate	SO_4	−2
Iodine	I	−1	Sulfite	SO_3	−2
Iron	Fe	+2 and 3	Chlorate(I)	ClO	−1
Lead	Pb	+2 and 4	Chlorate(V)	ClO_3	−1
Magnesium	Mg	+2	Vanadate(V)	VO_3	−1
Manganese	Mn	+2 and 4	Manganate(VII)	MnO_4	−1
Mercury	Hg	+1 and 2	Chromate(VI)	CrO_4	−2
Nitrogen	N	3 and 5	Dichromate(VI)	Cr_2O_7	−2
Oxygen	O	−2			
Potassium	K	+1			
Silver	Ag	+1			
Sodium	Na	+1			

The number of covalent bonds normally formed by an element

Element	Number of bonds
Hydrogen	1
Halogens (F, Cl, Br, I)	1
Oxygen	2
Sulfur	2 or more
Nitrogen	3
Phosphorus	3 or 5
Carbon	4
Silicon	4

Exercise 2: Writing formulae from names

Use the data in the table *Symbols and charges of common elements and ions* to write the formulae of the following. Before you start this exercise, make sure you have read *Section 3*: *Naming of compounds*.

1	Sodium chloride
2	Sodium hydroxide
3	Sodium carbonate
4	Sodium sulfate
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 sulfate
19	Calcium carbonate
20	Barium chloride
21	Barium sulfate
22	Aluminium chloride
23	Aluminium oxide
24	Aluminium hydroxide
25	Aluminium sulfate
26	Copper(II) sulfate
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) sulfide
47	Tin(II) chloride
48	Tin(IV) chloride
49	Iron(II) sulfate
50	Iron(II) chloride
51	Iron(III) sulfate
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 sulfate
60	Ammonium phosphate
61	Phosphorus trichloride
62	Phosphorus pentachloride
63	Phosphorus trioxide
64	Phosphorus pentoxide
65	Hydrogen phosphate (Phosphoric acid)
66	Hydrogen sulfate (Sulfuric acid)
67	Hydrogen nitrate (Nitric acid)
68	Hydrogen chloride (Hydrochloric acid)
69	Carbon tetrachloride
70	Silicon tetrachloride

71	Silicon dioxide
72	Sulfur dioxide
73	Sulfur trioxide
74	Hydrogen sulfide
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 GCE Level you will meet many compounds that are new to you and a lot of these will be organic compounds. In this section, you will look at the naming of compounds 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 of an inorganic compound must show which elements are present and, where confusion is possible, the oxidation state (or charge) of the elements concerned.

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

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** which 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 oxidation state (or charge) this may need to be shown. For example as iron can have charge +2 or +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 oxidation state (or charge) 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 **$FeCl_3$**. Other examples are:

$PbCl_2$	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	**Sulfur Dioxide.** This could be called **Sulfur(IV) Oxide**
SO_3	is	**Sulfur Trioxide**. This could be called **Sulfur(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**
$SiCl_4$	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 in the table *Symbols and charges of common elements and ions*. To cover the ideas we will look at the following groups.

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

A compound of sodium, carbon and oxygen would be Na_2CO_3 and would be called **Sodium Carbonate**. For example:

$NaNO_3$ is **Sodium Nitrate**

$Mg(NO_3)_2$ is **Magnesium Nitrate**

$Fe_2(SO_4)_3$ is **Iron(III) Sulfate**

$FeSO_4$ is **Iron(II) Sulfate.**

5 As most **non-metals** can have more than one oxidation state (or charge). For example sulfur can form **sulfates** and **sulfites.** 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 oxygen atoms. **Sulfate** can also be referred to as **sulfate(VI)** and **sulfite** can also be referred to as **sulfate(IV).** In the case of nitrogen with oxygen the compounds would be **nitrate** and **nitrite** or **nitrate(V)** and **nitrate(III).**

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

KNO_2 is **Potassium Nitrite** or **Potassium Nitrate(III)**

Na_2SO_3 is **Sodium Sulfite** or **Sodium Sulfate(IV)**

K_2CrO_4 is **Potassium Chromate(VI)**

$KMnO_4$ is **Potassium Manganate(VII)**

$KClO_3$ is **Potassium Chlorate(V).**

In summary

Common name	Systematic name	Formulae
Sulfate	Sulfate(VI)	$-SO_4$
Sulfite	Sulfate(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, because the properties of the two groups of compounds will be very different. In some cases use of the wrong compound in a reaction can 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.

6 When a compound is being considered it is usual to write the metal down first, both in the name and the formula. The exceptions to this 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.** The **ammonium** group has the formula $\mathbf{NH_4^+}$ and sits in the place generally taken by a metal in a formula.

NH_4Cl is **Ammonium Chloride**

$(NH_4)_2SO_4$ is **Ammonium Sulfate**

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

Sulfuric 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.

9 Organic compounds have their own set of naming and 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.

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 *Symbols and charges of common elements and ions* and the copy of the periodic table in *Section 12* to write the names of the following formulae. Before you start this exercise make sure you have read *Section 2*: C*hemical formulae*.

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 the volume of a gas. However, chemists find it convenient to use a unit called a ***mole***. You need to know and be able to use several definitions of a mole.

- 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 6.02×10^{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 atmospheric pressure contain the same number of moles or molecules. If the volume is 24 dm^3, at room temperature and pressure, this number, 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 using moles

These calculations form the basis of many of the calculations you will meet in your Advanced Level course.

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 and in this case it is 16 g mol^{-1}.*

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

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

= 4 moles of oxygen atoms

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

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

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}

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

= **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 + 32.1 + (4 x 16) + 5{(2x1) + 16}] = 249.6 g mol^{-1}

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

= **0.4006 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 sulfur dioxide SO_2.

1 mole of sulfur dioxide has a mass = 32.1 + (2 x 16) = 64.1 g mol^{-1}

∴ 3 moles of SO_2 = 3 x 64.1 **= 192.3 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) + (32.1 x 2) + (16 x 3)] + 5[(2 x 1) +16] = 248.2 g mol^{-1}

∴ 0.05 moles of $Na_2S_2O_3.5H_2O$ = 0.05 x 248.2 **= 12.41 g**

Example 3

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

You will be given the information that **1 mole of any gas has a volume of 24 dm^3 (24,000 cm^3) at room temperature and pressure**.

$\therefore$	**The volume of a given number of moles of gas**	**=**	**number of moles**	**x**	**24 000 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.

$\therefore$ 2 moles of carbon dioxide = 2 x 24 000 cm^3 = 48 000 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 24 000 cm^3 **= 134.4 cm^3**

Example 4

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

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

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

For this calculation you need 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 24 000 cm^3 = 120 000 cm^3 **= 120 dm^3**

Example 6

Calculation of the mass of a given volume of gas

For this calculation you need 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

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

For example, 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	0.641 g of SO_2
7	80.1 g of SO_3
8	18.20 g of HBr
9	0.0981 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	17.77 g of Na_2SO_4

16	3.16 g of $KMnO_4$
17	32.36 g of K_2CrO_4
18	100.1 g of $KHCO_3$
19	7.63 g of KI
20	3.90 g of $CsNO_3$
21	0.1111 g of $CaCl_2$
22	41.025 g of $Ca(NO_3)_2$
23	1.482 g of $Ca(OH)_2$
24	3.405 g of $CaSO_4$
25	41.66 g of $BaCl_2$
26	14.96 g of $CuSO_4$
27	13.64 g of $ZnCl_2$
28	1.434 g of $AgNO_3$
29	13.76 g of NH_4Cl
30	13.77 g of $(NH_4)_2SO_4$
31	23.4 g of NH_4VO_3
32	10.01 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	3.076 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	8.36 g of $Al_2(SO_4)_3$
49	3.8 g of $FeSO_4$
50	199.7 g of $FeCl_2$

Exercise 4b: Calculation of the mass of material in a given number of moles of at 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 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 volume of a given mass of gas

In each case calculate the volume in 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 4f: 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 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.

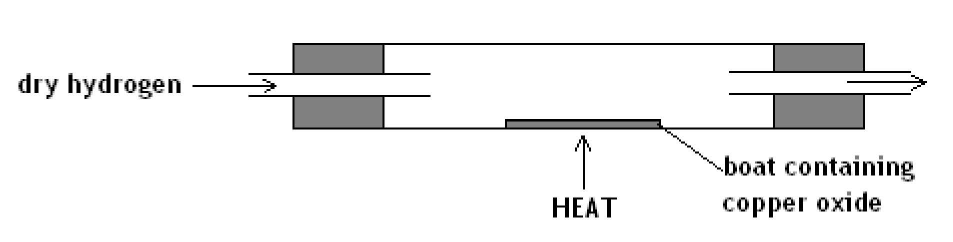
(Assume that all volumes are measured at room temperature and pressure and that 1 mol of gas has a volume of 24 000 cm^3 under these conditions.)

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.
- Copper(II) oxide 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 produced 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 oxidised to copper(II) oxide.

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

Typical results

Mass of copper (II) oxide	= 4.97 g
Mass of copper	= 3.97 g
Mass of oxygen	= 1.00 g

	÷ by relative atomic mass (r.a.m)	÷ by smallest	Ratio of atoms
Moles of copper atoms	$\frac{3.97}{63.5}=0.0625$	$\frac{0.0625}{0.0625}=1$	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 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 not presented as mass, but as a percentage composition of the elements concerned. In these cases, the calculation is carried out in the same way as percentage composition is 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?

NB: This is an oxide of sodium. It must only contain 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

Molecular Formula Mass	=	78
Empirical Formula Mass	=	(Na + O) = 23 + 16 = 39
∴ 78	=	39 x n
∴ n	=	2

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 include all 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 but 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 of the calculation. For example NH_4OH and NH_2OH have a 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 need to check your calculation.

Example 3

Calculate the empirical formula of a compound with the 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 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

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

You need to be careful about this; the factors will generally be clear and will be 2 or 3. You must not 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

24.64 grams of a hydrated salt of $MgSO_4 . xH_2O$, gives 12.04 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 = 24.64 − 12.04 = 12.60 g

	$MgSO_4$	H_2O
	12.04	12.60
Divide by M_r	$\frac{12.04}{120.4}$	$\frac{12.60}{18}$
	= 0.100	= 0.700
Ratio of atoms	1	7

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

Exercise 5: Calculation of formulae from experimental data

In *Section a,* calculate the empirical formula of the compound from the given data. 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, find the empirical formula and then the molecular formula. *Section c.* is more difficult. The data is presented in a different way 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	3.348 g of iron join with 1.44 g of oxygen in an oxide of iron that has a M_r = 159.6 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 sulfur 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?

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) sulfate is heated it produces 9.60 g of anhydrous copper(II) sulfate. 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 us what reacts with what in a chemical reaction. They tell us how many of each type of molecule are needed and produced, so they also tell us 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:

$$\text{hydrogen} \quad + \quad \text{oxygen} \quad \rightarrow \quad \text{water}$$

Writing formulae

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

- hydrogen is represented as H_2
- oxygen is represented as O_2
- water is H_2O.

So we get:

$$H_2 \quad + \quad O_2 \quad \rightarrow \quad H_2O$$

However, this will not suffice 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 a chemical equation you must have the same number of each kind of atoms 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:

$$\text{carbon} \quad + \quad \text{oxygen} \quad \rightarrow \quad \text{carbon dioxide}$$

$$C \quad + \quad O_2 \quad \rightarrow \quad CO_2$$

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) – therefore 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, O_2, but magnesium oxide has just one atom of oxygen per molecule and is therefore written as MgO.

$$Mg + O_2 \rightarrow MgO$$

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 but 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 adding in *state symbols*: (aq) for aqueous solution, (g) for gas, (l) 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 in the first six questions where numbers need to be inserted to achieve the balance. In one or two difficult cases some of the numbers have been added. You will not need to change these. Remember all the formulae are correct!

1	_ H_2	+	O_2	$\rightarrow$	_ H_2O				
2	$BaCl_2$	+	_ $NaOH$	$\rightarrow$	$Ba(OH)_2$	+	_ $NaCl$		
3	H_2SO_4	+	_ KOH	$\rightarrow$	_ K_2SO_4	+	H_2O		
4	K_2CO_3	+	_ HCl	$\rightarrow$	_KCl	+	H_2O	+	CO_2
5	$CaCO_3$	+	_HNO_3	$\rightarrow$	$Ca(NO_3)_2$	+	H_2O	+	CO_2
6	Ca	+	_H_2O	$\rightarrow$	$Ca(OH)_2$	+	H_2		
7	$Pb(NO_3)_2$	+	NaI	$\rightarrow$	PbI_2	+	$NaNO_3$		
8	$Al_2(SO_4)_3$	+	$NaOH$	$\rightarrow$	$Al(OH)_3$	+	Na_2SO_4		
9	$Al(OH)_3$	+	$NaOH$	$\rightarrow$	$NaAlO_2$	+	H_2O		
10	$Pb(NO_3)_2$	$\rightarrow$	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	$\rightarrow$	NH_3					
24	$NaBr$	+	H_2SO_4	$\rightarrow$	Na_2SO_4			+	HBr	
25	HBr	+	H_2SO_4	$\rightarrow$	H_2O			+	SO_2	+ Br_2
26	C_2H_5OH	+	PCl_3	$\rightarrow$	C_2H_5Cl			+	H_3PO_3	
27	Fe_3O_4	+	H_2	$\rightarrow$	Fe			+	H_2O	
28	Fe_2O_3	+	CO	$\rightarrow$	Fe			+	CO_2	
29	C_2H_5OH	+	CH_3CO_2H	$\rightarrow$	$CH_3CO_2C_2H_5$			+	H_2O	
30	$2KMnO_4$	+	HCl	$\rightarrow$	$MnCl_2$	+	Cl_2	+	$8H_2O$	+ KCl

Exercise 6b: What's wrong here?

The following equations all contain one or more mistakes. These may be in a formula, in the balancing, in the state symbols or even in the chemistry. You need to identify the error and then write out a correct equation.

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

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, and you will need to write more than one equation.

1 Zinc metal reacts with copper sulfate solution to produce solid copper metal and zinc sulfate 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 questions in this exercise will need a lot of thought as they involve changes in the oxidation state (charge) of the elements concerned. Before you start to balance the equations check with your teacher that you have the formulae correct.

9 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.

10 Concentrated sulfuric acid reacts with solid potassium iodide to produce solid potassium hydrogen sulfate, iodine vapour, water and hydrogen sulfide 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 were all originally found 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 1 mole of oxygen molecules and produce 2 moles of magnesium oxide.

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

- *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, 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.

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 need to calculate the ratio of the reacting moles and then use these to write out 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 $Pb(NO_3)_2$	= (3.31/331.2) mol	= 0.010 mol
	1.17 g of NaCl	= (1.17/58.5) mol	= 0.020 mol
	2.78 g of $PbCl_2$	= (2.78/278.2) 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 $NaNO_3$

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

You do not need to write all of this out each time.

2 When 5.175 g of lead are heated to 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 this type of question you seem to be short of information but in fact you know the mass of oxygen reacting. Remember it 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	= (5.175/207.2) 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 all the information needed to write the full equation but as you know there is only 1 product and this has 3 lead atoms and 4 oxygen atoms, you can suggest a formula.

3 25 cm^3 of 2 mol dm^{-3} sulfuric acid solution react with 50 cm^3 of 2 mol dm^{-3} sodium hydroxide solution to produce sodium sulfate and water. Construct the equation for this reaction.

You will need to look at the start of section 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 x 10^{-5} mol
6 cm^3 of hydrogen	= (6/24000) mol	= 2.50 x 10^{-4} mol
4 cm^3 of ammonia	= (4/24000) mol	= 1.67 x 10^{-4} mol

$\therefore$ ratios are	(8.33 x 10^{-5}/8.33 x 10^{-5}) of nitrogen	= 1
	(2.50 x 10^{-4}/8.33 x 10^{-5}) of hydrogen	= 3
	(1.67 x 10^{-4}/8.33 x 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/ 100.1 mol of $CaCO_3$	+	(10x2)/1000 mol of HNO_3	$\rightarrow$	1.64/164.1 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, and 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 out 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 out 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. This is because phenolphthalein changes colour when a different number of hydrogen ions in the acid have reacted, and a different salt forms.

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

---

ii Suggest the formula of the salt produced in each case.

---

iii Write out 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) sulfate, $CuSO_4.xH_2O$, was heated 7.980 g of anhydrous salt were produced. Use the data to find the value of x and write out the equation for the reaction.

7 When 20 cm^3 of 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 out 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 the reacting moles in the equation and suggest values for a and b.

9 When 8.4 g of sodium hydrogen carbonate are heated 5.30 g of solid residue and 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 sulfur dioxide and 2.0 g of sulfur trioxide. The rest of the mass loss being due to the water of crystallization being lost. Use the data to write out the full equation for the action of heat.

Section 8: Amounts of substances

Equations can also tell us 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 in *Section 12*). 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 out 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

$\therefore$ (2 x 24.3g) of magnesium gives 2 x (24.3 + 16) = 80.6 g of Magnesium oxide

$\therefore$ 16 g of magnesium gives $\dfrac{80.6 \times 16}{2 \times 24.3}$ = **26.5 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 24 000 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 react with 1 mole of O_2

$\therefore$2 x 24.3 g of Mg react with 1 x 24 000 cm^3 of O_2(g)

$\therefore$ 16 g of Mg react with $\dfrac{1 \times 24\,000 \times 16}{2 \times 24.3}$ = **7901 cm^3 of oxygen**

Example 2

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

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

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

$\therefore$ 331.2 g of lead nitrate gives 303.2 g of lead sulfate

$\therefore$ 10 g of lead nitrate gives $\dfrac{303.2 \times 10 \text{ g of lead sulfate}}{331.2}$ = **9.15 g of lead sulfate**

Example 3

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

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

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 169.9 g of silver nitrate give 3 x 24000 cm^3 of gas

$\therefore$ 1 g of silver nitrate gives $\dfrac{3 \times 24000 \text{ cm}^3 \times 1\text{g of gas}}{2 \times 169.9}$ = **211.9 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 expressed as moles in the equation.

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

$\therefore$ 2 moles of sodium hydroxide give 1 mole of the crystals of sodium carbonate

$\therefore$ 2 x 40 g of sodium hydroxide give 286 g of crystals

$\therefore$ 5 g of sodium hydroxide gives $\dfrac{286 \times 5}{2 \times 40}$ = **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 but 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.

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

$\therefore$ 88 g of ethyl ethanoate are produced from 60 g of ethanoic acid and 46 g of ethanol

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

and $\dfrac{46\,\text{g} \times 100\,\text{g}}{88\,\text{g}}$ = **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.

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1 What mass of barium sulfate 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 react together to give 1 g of ethyl ethanoate?

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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 sulfate 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 15.96 g of copper sulfate 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 33.12 g of lead(II) nitrate ?
10	Magnesium reacts with sulfuric acid to produce a solution of magnesium sulfate. If this is allowed to crystallise out the solid produced has the formula $MgSO_4.7H_2O$. Write out the equation for this reaction and calculate the mass of magnesium sulfate heptahydrate that could be produced from 4 g of magnesium.
11	Copper(II) oxide reacts with sulfuric acid to produce copper(II) sulfate. 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	Sulfur 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 sulfur 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 (V) chlorate would 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 = 1×10^6 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 deposit 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 10 000 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 volume 24 000 cm^3, at room temperature and 1 atmosphere pressure**. (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

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

This makes 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 sulfur trioxide would be produced by the complete reaction of 100 cm^3 of sulfur dioxide with oxygen? What volume of oxygen would be needed to just react with the sulfur 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 sulfur dioxide will need 50 cm^3 of oxygen and will produce 100 cm^3 of sulfur 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 sulfur dioxide needs only 50 cm^3 of oxygen there must be 50 cm^3 of unused oxygen. Thus, the final volume is:

100 cm^3 of sulfur 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 an 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.

	$N_2(g)$	+	$3H_2(g)$	$\rightarrow$	$2NH_3(g)$
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	+	$2O_2$	$\rightarrow$	CO_2	+	$2H_2O$
2	C_2H_4	+	$3O_2$	$\rightarrow$	$2CO_2$	+	$2H_2O$
3	$2C_2H_2$	+	$5O_2$	$\rightarrow$	$4CO_2$	+	$2H_2O$
4	$2C_8H_{18}$	+	$25O_2$	$\rightarrow$	$16CO_2$	+	$18H_2O$
5	N_2	+	$3H_2$	$\rightarrow$	$2NH_3$		

Section b

In *Section b,* you need 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 sulfuric acid, sulfur dioxide is converted to sulfur trioxide by reaction with oxygen in the air. What volume of air (assume 20% of the air is oxygen) would be needed to produce 150 cm^3 of sulfur trioxide? Assume complete conversion of sulfur dioxide to sulfur trioxide.

---

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

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

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 burned with 30 cm^3 of oxygen?

Section 10: Ions and ionic equations

Ionic theory

Many of the chemicals you will use at GCE Advanced Level 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 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 for example hydrogen chloride and sulfuric acid.

Structures of ionic compounds

During your course you will study bonding and structure, and some 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 the 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 found in them. For example 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

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

Let us look at a molecular equation and see how it may be converted into an ionic equation. For example, look at the reaction between iron (II) sulfate 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) sulfate 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 sulfate 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 as:

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

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) sulfate 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 and finished in the solution. 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 need to balance the equations, in Questions 6–10 you need to complete the equation and then balance it. For Questions 1–17 you need to write the full, balanced ionic equation. Questions 18–20 involve more complex ions and again just need 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 out an ionic equation for the reaction of magnesium with sulfuric acid.

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

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

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

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

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

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

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

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

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

Section 11: Calculations involving chemicals in solution

Experiments measuring concentrations of chemicals in solution 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 solutions of known concentration.

Concentration in solution is generally measured as moles per 1000 cm^3 **of solution**. For example, sodium chloride may be labelled as 1M NaCl. This means that each 1000 cm^3 of the solution contains 1 mole of NaCl (58.5 g), or its concentration is 1 mol dm^{-3}.

It does not mean that 58.5 g of NaCl have been added to 1000 cm^3 of water as the volume of the mixture may no longer be 1000 cm^3.

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 more 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**.

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

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

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

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

Method

To carry out these calculations, you need to calculate the actual amounts of materials in the volumes involved.

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?

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

$\therefore$ 2 mol of NaOH react with 1 mol of H_2SO_4.

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

$\therefore$ 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

$\therefore$ 1.25 x 10^{-3} moles of H_2SO_4 will be found in 50 cm^3 of the solution.

$\therefore$ In 1000 cm^3 of the acid the same solution there will be

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

$$= \quad 0.0250 \text{ moles}$$

$\therefore$ The concentration of the sulfuric 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 given volume of solution.

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	6.624 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	1.962 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 out the equation for the reaction taking place
- calculating the number of moles in the solution whose molarity is given
- calculating the number of moles of the substance in the first named solution using the reacting ratio in the chemical equation
- finally, calculating the number of moles in 1 dm^3 (the molarity).

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} sulfuric 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 sulfate 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 sulfate solution? The ionic equation for the reaction is $5Fe^{2+} + MnO_4^-(aq) + 8H^+(aq) \rightarrow 5Fe^{3+}(aq) + Mn^{2+}(aq) + 4H_2O(l)$		
15	10 cm^3 of a solution of NaCl reacts 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 reacts 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? See Question 14 for the equation for this reaction.		

For last five questions you will need to use the skills you have learnt in this section, together with those from other sections as appropriate.

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: The periodic table of the elements

The Periodic Table of Elements

Key

relative atomic mass **atomic symbol** name atomic (proton) number

1	2											3	4	5	6	7	0 (8)
							1.0 **H** hydrogen 1										*(18)* 4.0 **He** helium 2
(1)	*(2)*											*(13)*	*(14)*	*(15)*	*(16)*	*(17)*	
6.9 **Li** lithium 3	9.0 **Be** beryllium 4											10.8 **B** boron 5	12.0 **C** carbon 6	14.0 **N** nitrogen 7	16.0 **O** oxygen 8	19.0 **F** fluorine 9	20.2 **Ne** neon 10
23.0 **Na** sodium 11	24.3 **Mg** magnesium 12	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*	*(12)*	27.0 **Al** aluminium 13	28.1 **Si** silicon 14	31.0 **P** phosphorus 15	32.1 **S** sulfur 16	35.5 **Cl** chlorine 17	39.9 **Ar** argon 18
39.1 **K** potassium 19	40.1 **Ca** calcium 20	45.0 **Sc** scandium 21	47.9 **Ti** titanium 22	50.9 **V** vanadium 23	52.0 **Cr** chromium 24	54.9 **Mn** manganese 25	55.8 **Fe** iron 26	58.9 **Co** cobalt 27	58.7 **Ni** nickel 28	63.5 **Cu** copper 29	65.4 **Zn** zinc 30	69.7 **Ga** gallium 31	72.6 **Ge** germanium 32	74.9 **As** arsenic 33	79.0 **Se** selenium 34	79.9 **Br** bromine 35	83.8 **Kr** krypton 36
85.5 **Rb** rubidium 37	87.6 **Sr** strontium 38	88.9 **Y** yttrium 39	91.2 **Zr** zirconium 40	92.9 **Nb** niobium 41	95.9 **Mo** molybdenum 38	[98] **Tc** technetium 43	101.1 **Ru** ruthenium 44	102.9 **Rh** rhodium 45	106.4 **Pd** palladium 46	107.9 **Ag** silver 47	112.4 **Cd** cadmium 48	114.8 **In** indium 49	118.7 **Sn** tin 50	121.8 **Sb** antimony 51	127.6 **Te** tellurium 52	126.9 **I** iodine 53	131.3 **Xe** xenon 54
132.9 **Cs** caesium 55	137.3 **Ba** barium 56	138.9 **La*** lathanum 57	178.5 **Hf** hafnium 72	180.9 **Ta** tantalum 73	183.8 **W** tungsten 74	186.2 **Re** rhenium 75	190.2 **Os** osmium 76	192.2 **Ir** iridium 77	195.1 **Pt** platinum 78	197.0 **Au** gold 79	200.6 **Hg** mercury 80	204.4 **Tl** thallium 81	207.2 **Pb** lead 82	209.0 **Bi** bismuth 83	[209] **Po** polonium 84	[210] **At** astatine 85	[222] **Rn** radon 86
[223] **Fr** francium 87	[226] **Ra** radium 88	[227] **Ac*** actinium 89	[261] **Rf** rutherfordium 104	[262] **Db** dubnium 105	[266] **Sg** seaborgium 106	[264] **Bh** bohrium 107	[277] **Hs** hassium 108	[268] **Mt** meitnerium 109	[271] **Ds** darmstadtium 110	[272] **Rg** roentgenium 111							

Elements with atomic numbers 112-116 have been reported but not fully authenticated

* Lanthanide series	140 **Ce** cerium 58	141 **Pr** praseodymium 59	144 **Nd** neodymium 60	[147] **Pm** promethium 61	150 **Sm** samarium 62	152 **Eu** europium 63	157 **Gd** gadolinium 64	159 **Tb** terbium 65	163 **Dy** dysprosium 66	165 **Ho** holmium 67	167 **Er** erbium 68	169 **Tm** thulium 69	173 **Yb** ytterbium 70	175 **Lu** lutetium 71
* Actinide series	232 **Th** thorium 90	[231] **Pa** protactinium 91	238 **U** uranium 92	[237] **Np** neptunium 93	[242] **Pu** plutonium 94	[243] **Am** americium 95	[247] **Cm** curium 96	[245] **Bk** berkelium 97	[251] **Cf** californium 98	[254] **Es** einsteinium 99	[253] **Fm** fermium 100	[256] **Md** mendelevium 101	[254] **No** nobelium 102	[257] **Lr** lawrencium 103

Section 13: Answers

Exercise 1

1	18	**21**	111.1	**41**	159.6
2	44	**22**	164.1	**42**	136.4
3	17	**23**	74.1	**43**	169.9
4	46	**24**	136.2	**44**	53.5
5	28	**25**	208.3	**45**	132.1
6	64.1	**26**	133.5	**46**	116.9
7	80.1	**27**	213	**47**	122.6
8	80.9	**28**	342.3	**48**	166.0
9	98.1	**29**	151.8	**49**	74.5
10	63	**30**	126.8	**50**	69.0
11	58.5	**31**	162.3	**51**	249.6
12	85	**32**	399.9	**52**	277.9
13	106	**33**	223.2	**53**	964
14	40	**34**	239.2	**54**	248.2
15	142.1	**35**	685.6	**55**	126
16	158	**36**	331.2	**56**	246.4
17	194.2	**37**	278.2	**57**	263.6
18	100.1	**38**	303.3	**58**	60
19	166	**39**	99.0	**59**	58
20	194.9	**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 Sulfur dioxide (or IV oxide)
7 Sulfur trioxide (or VI oxide)
8 Hydrogen chloride
9 Hydrogen iodide
10 Hydrogen fluoride
11 Methane
12 Hydrogen sulfide
13 Hydrogen bromide
14 Sulfuric acid
15 Nitric acid
16 Sodium chloride
17 Sodium nitrate
18 Sodium carbonate
19 Sodium hydroxide
20 Sodium sulfate
21 Calcium chloride
22 Calcium nitrate
23 Calcium hydroxide
24 Calcium sulfate
25 Barium chloride
26 Aluminium chloride
27 Aluminium nitrate
28 Aluminium sulfate
29 Iron(II) sulfate
30 Iron(II)chloride
31 Iron(III) chloride
32 Iron(III) sulfate
33 Lead(II) oxide
34 Lead(IV) oxide
35 Lead(II) nitrate
36 Lead(II) chloride
37 Lead (II) sulfate
38 Copper(II) nitrate
39 Copper(I) chloride
40 Copper(II) chloride
41 Copper(II) sulfate
42 Zinc chloride
43 Silver nitrate
44 Ammonium chloride
45 Ammonium sulfate
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
2	2.0
3	0.10
4	5.0
5	20
6	0.010
7	1.0
8	0.22
9	0.0010
10	0.050
11	0.33
12	0.25
13	0.021
14	0.020
15	0.125
16	0.020
17	0.167
18	1.0
19	0.046
20	0.020
21	0.0010
22	0.25
23	0.02
24	0.0025
25	0.20
26	0.10
27	0.10
28	0.0085
29	0.26
30	0.104
31	0.20
32	0.082
33	0.050
34	1.34
35	0.025
36	0.204
37	0.071
38	0.010
39	0.050
40	0.254
41	0.0125
42	0.152
43	0.10
44	0.053
45	0.0043
46	0.036
47	0.266
48	0.024
49	0.025
50	1.574

Exercise 4b

1	36 g	**26**	15.96 g
2	132 g	**27**	76.38 g
3	47.6 g	**28**	10.02 g
4	23 g	**29**	17.82 g
5	33.6 g	**30**	145.31 g
6	41.02 g	**31**	2.922 g
7	240.3 g	**32**	12.26 g
8	80.9 g	**33**	21.4 g
9	1.177g	**34**	745 g
10	9.45 g	**35**	0.069 g
11	26.3 g	**36**	49.92 g
12	59.5 g	**37**	27.79 g
13	11.66 g	**38**	4.82 g
14	80.0 g	**39**	9.928 g
15	127.9 g	**40**	302.4 g
16	7.9 g	**41**	757.68 g
17	34.96 g	**42**	39.54 g
18	90.1 g	**43**	10.2 g
19	249 g	**44**	11.6 g
20	23.39g	**45**	9.76 g
21	12.22g	**46**	4.34 g
22	672.8 g	**47**	9.59 g
23	0.296 g	**48**	41.08 g
24	13.62 g	**49**	303.8 g
25	43.74 g	**50**	1394.8 g

Exercise 4c

1	24 000 cm^3	**11**	134.4 cm^3
2	2400 cm^3	**12**	216 cm^3
3	12 000 cm^3	**13**	960 cm^3
4	48 000 cm^3	**14**	2952 cm^3
5	2880 cm^3	**15**	55.2 cm^3
6	81 600 cm^3	**16**	192 000 cm^3
7	2640 cm^3	**17**	0.24 cm^3
8	96 cm^3	**18**	144 000 cm^3
9	240 000 cm^3	**19**	182.4 cm^3
10	10 800 cm^3	**20**	72 000 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**	56 000 cm^3
2	7059 cm^3	**12**	30 545 cm^3
3	8571 cm^3	**13**	20 308 cm^3
4	7500 cm^3	**14**	16 000 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	30 000 cm^3	**18**	12 000 cm^3
9	2 400 000 cm^3	**19**	26 526 cm^3
10	180 000 cm^3	**20**	77 143 cm^3

Exercise 4g

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

13 C_2H_4

14 C_3H_6

15 P_2I_4

16 $N_2H_4S_2O_8$

17 P_4O_{10}

18 $C_2H_4O_2 - CH_3COOH$

19 C_4H_{10}

20 Fe_2O_3

21 $H_2S_2O_8$

22 C_6H_6

Section (c)

23 PbO

24 KO_2

25 C_2H_2

26 $AlCl_3$

27 CH_4

28 yes

29 $CuSO_4$ $5H_2O$

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

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 charge 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 charge of 3 not 2 as in this equation.

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

9 Sodium has a charge 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	$AlCl_3$	+	$3AgNO_3$	$\rightarrow$	$Al(NO_3)_3$	+	$3AgCl$	
2	K_2CrO_4	+	$Pb(NO_3)_2$	$\rightarrow$	$PbCrO_4$	+	$2KNO_3$	
3	$2AgNO_3$	$\rightarrow$	$2Ag$	+	$2NO_2$	+	O_2	
4	i) 1 mole							
	ii) 2 moles							
	iii)							
	H_3PO_4	+	$NaOH$	$\rightarrow$	NaH_2PO_4	+	H_2O	
	H_3PO_4	+	$2NaOH$	$\rightarrow$	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	$4NH_3$	+	$5O_2$	$\rightarrow$	$4NO$	+	$6H_2O$	
8	C_3H_8	+	$5O_2$	$\rightarrow$	$3CO_2$	+	$4H_2O$	
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 21.59 g

3 0.682 g of ethanoic acid and 0.523 g of ethanol

4 143 tonnes

5 14.52 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 4.15×10^6 dm^3 of nitrogen, 12.5×10^6 dm^3 of hydrogen

19 63 tonnes of nitric acid, 4.8×10^7 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 $^5/_4 \times 2500 = 3125cm^3$ $O_2 \rightarrow 15\,625cm^3$ air

4 $6.5 \times 24\,000cm^3 = 156m^3$

5 $24\,000cm^3$

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 11

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

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