Taverham Sixth Form
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A-Level Chemistry Calculation Booklet

Name ……………………………………………………………………………

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You must complete this booklet and bring it with you to your first class in September

Section 1: Molar Mass

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. 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 H_2SO_4

5 HNO_3

6 $NaNO_3$

7 Na_2CO_3

8 $NaOH$

9 Na_2SO_4

10 $Al(NO_3)_3$

11 $Al_2(SO_4)_3$

12 $FeSO_4$

13 $Fe_2(SO_4)_3$

14 PbO

15	PbO_2
16	Pb_3O_4
17	$Pb(NO_3)_2$
18	$PbCl_2$
19	$PbSO_4$
20	$CuCl$
21	$CuCl_2$
22	$CuSO_4$
23	$ZnCl_2$
24	$AgNO_3$
25	NH_4Cl
26	$(NH_4)_2SO_4$
27	$CuSO_4.5H_2O$

Section 2: Chemical Formulae

A chemical formula is a useful shorthand method for describing the atoms in a chemical. Sometimes you will see the formula used instead of the name, but you should not do this if you are asked for a name. The chemical formula of an element or compound tells you:

- which elements it contains eg $FeSO_4$ contains iron, 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 16g 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 nonmetal 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 two 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 A-level course or that are mentioned in some of the calculations in this workbook.

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	Hydrogencarbonate	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 bromide
36	Silver iodide
37	Silver nitrate
38	Silver oxide
39	Lead(II) nitrate
40	Lead(II) carbonate
41	Lead(II) oxide
42	Lead(IV) oxide
43	Lead(II) chloride
44	Lead(IV) chloride
45	Lead(II) sulfide
46	Tin(II) chloride

47	Tin(IV) chloride
48	Iron(II) sulfate
49	Iron(III) chloride
50	Iron(III) hydroxide
51	Ammonium chloride
52	Ammonium carbonate
53	Ammonium hydroxide
54	Ammonium nitrate
55	Ammonium sulfate
56	Ammonium phosphate
57	Phosphorus trichloride
58	Phosphorus pentachloride
59	Phosphorus trioxide
60	Phosphorus pentoxide
61	Hydrogen phosphate (Phosphoric acid)
62	Hydrogen sulfate (Sulfuric acid)

63	Hydrogen nitrate (Nitric acid)
64	Hydrogen chloride (Hydrochloric acid)
65	Carbon tetrachloride
66	Silicon tetrachloride
67	Silicon dioxide
68	Sulfur dioxide
69	Sulfur trioxide
70	Hydrogen sulfide
71	Chlorine(I) oxide
72	Nitrogen dioxide
73	Nitrogen monoxide
74	Carbon dioxide
75	Carbon monoxide
76	Hydrogen hydroxide

Section 3: Naming of Compounds

At A-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. 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 i**ron(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 monoxide** where mon- means one
CO_2	is	**carbon dioxide** 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 **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_2H5OH	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 periodic table to write the names of the following formulae. Before you start this exercise make sure you have read *Section 2: Chemical 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	CH_4	

10	H_2S
11	H_2SO_4
12	HNO_3 (aq)
13	NaCl
14	$NaNO_3$
15	Na_2CO_3
16	NaOH
17	Na_2SO_4
18	$CaCl_2$
19	$Ca(NO_3)_2$
20	$CaSO_4$
21	$BaCl_2$
22	$AlCl_3$
23	$Al(NO_3)_3$
24	$Al_2(SO_4)_3$
25	$FeSO_4$
26	$FeCl_2$
27	$FeCl_3$

28	$Fe_2(SO_4)_3$
29	PbO
30	PbO_2
31	$Pb(NO_3)_2$
32	$AgNO_3$
33	NH_4Cl
34	$(NH_4)_2SO_4$
35	NH_4VO_3 (V is Vanadium)
36	$KClO_3$
37	KIO_3
38	C_2H_6
39	C_4H_{10}
40	C_8H_{18}
41	$(NH_4)_2CO_3$
42	$KMnO_4$
43	K_2CrO_4
44	$KHCO_3$

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 A-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

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

$$\therefore \text{numberofmolesofoxygen} = \frac{\text{64 g of oxygen atoms}}{\text{molarmassofoxygenof16gmol}^{-1}}$$

= 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}

$$\therefore \text{number of moles of chlorine} = \frac{142 \text{gofchlorinegas}}{\text{molarmassofchlorineof71gmol}^{-1}}$$

= 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}

$$\therefore \text{numberofmolesof}CuSO_4.5H_2O = \frac{100\text{gof}CuSO_4.5H_2O}{\text{molecularmassof}CuSO_4.5H_2O\text{of249.5gmol}^{-1}}$$

= **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}

$\therefore$ 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}

$\therefore$ 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**.

∴	**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.

∴ 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

$$\text{number of moles of gas} = \frac{\text{volumeofgasincm}^3}{24000\text{cm}^3}$$

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

$$\text{Number of moles} = \frac{240\text{cm}^3}{24000\text{cm}^3} = 0.010\text{moles}$$

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

$$\text{Number of moles of gas} = \frac{1000\text{cm}^3}{24000\text{cm}^3} = 0.0147\text{moles}$$

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

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

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

∴ 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

$$\therefore \text{ number of moles of } CO_2 = \frac{1000\text{cm}^3 \text{ of } CO_2 \text{ volume of 1 mole of } CO_2 \text{ of } 24000\text{cm}^3}{}$$

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

∴ 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.

$$\therefore 24000\text{cm}^3 \text{ of the gas must have a mass of } = \frac{0.0667\text{g} \times 24000\text{cm}^3}{100\text{cm}^3}$$

$$= 16 \text{ g}$$

∴ 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 mg of $CaSO_4$
25	41.66 kg of $BaCl_2$
26	14.96 µg of $CuSO_4$
27	13.64 g of $ZnCl_2$
28	1.434 mg of $AgNO_3$
29	13.76 kg of NH_4Cl
30	13.77 g of $(NH_4)_2SO_4$
31	23.4 g of NH_4VO_3

Exercise 4b: calculation of the mass of material in a given number of moles of that 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	0.90 moles of Na_2SO_4

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

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

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

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

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

Section 5: 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**.

$$\text{molarity} = \frac{\text{concentrationingramsper1000cm}^3}{M_r \text{ for the material dissolved}}$$

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

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

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

Exercise 5a: 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} $\underline{HCl}$
2	50 cm^3 of 0.5 mol dm^{-3} $\underline{HCl}$
3	250 cm^3 of 0.25 mol dm^{-3} $\underline{HCl}$
4	500 cm^3 of 0.01 mol dm^{-3} $\underline{HCl}$
5	25 cm^3 of 1.0 mol dm^{-3} $\underline{NaOH}$
6	50 cm^3 of 0.5 mol dm^{-3} $\underline{KOH}$
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} $\underline{FeSO_4}$

Exercise 5b: calculate the mass of material in the given volume of solution

1	25 cm^3 of 1 mol dm^{-3} HCl
2	50 cm^3 of 0.5 mol dm^{-3} $NaCl$
3	100 cm^3 of 0.25 mol dm^{-3} NH_4NO_3
4	100 cm^3 of 0.1 mol dm^{-3} $AgNO_3$
5	25 cm^3 of 1 mol dm^{-3} $BaCl_2$
6	50 cm^3 of 0.2 mol dm^{-3} H_2SO_4
7	20 cm^3 of 0.1 mol dm^{-3} $NaOH$
8	50 cm^3 of 0.1 mol dm^{-3} K_2CrO_4
9	25 cm^3 of 0.02 mol dm^{-3} $KMnO_4$
10	25 cm^3 of 0.1 mol dm^{-3} $Pb(NO_3)_2$

Exercise 5c: what is the concentration in moles dm^{-3} of the following?

1	3.65 g of HCl in 1000 cm^3 of solution
2	3.65 g of HCl in 100 cm^3 of solution
3	6.624 g of $Pb(NO_3)_2$ in 250 cm^3 of solution
4	1.00 g of NaOH in 250 cm^3 of solution
5	1.962 g of H_2SO_4 in 250 cm^3 of solution
6	1.58 g of $KMnO_4$ in 250 cm^3 of solution
7	25.0 g of $Na_2S_2O_3.5H_2O$ in 250 cm^3 of solution
8	25.0 g of $CuSO_4.5H_2O$ in 250 cm^3 of solution
9	4.80 g of $(COOH)_2.2H_2O$ in 250 cm^3 of solution
10	10.0 g of $FeSO_4.(NH_4)_2SO_4.6H_2O$ in 250 cm^3 of solution
11	240 cm^3 of $NH_3(g)$ dissolved in 1000 cm^3 of solution
12	480 cm^3 of HCl(g) dissolved in 100 cm^3 of solution

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:

hydrogen + oxygen → 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:

$$H_2 + O_2 \rightarrow H_2O$$

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:

carbon + oxygen → carbon dioxide

$$C + O_2 \rightarrow CO_2$$

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 → 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	→	_ H_2O				
2	$BaCl_2$	+	_ NaOH	→	$Ba(OH)_2$	+	_ NaCl		
3	H_2SO_4	+	_ KOH	→	_ K_2SO_4	+	H_2O		
4	K_2CO_3	+	_ HCl	→	_KCl	+	H_2O	+	CO2
5	$CaCO_3$	+	_HNO_3	→	$Ca(NO_3)_2$	+	H_2O	+	CO2
6	Ca	+	_H_2O	→	$Ca(OH)_2$	+	H_2		
7	$Pb(NO_3)_2$	+	NaI	→	PbI_2	+	$NaNO_3$		
8	$Al_2(SO_4)_3$	+	NaOH	→	$Al(OH)_3$	+	Na_2SO_4		
9	$4HNO_3$	+	Cu	→	$Cu(NO_3)_2$	+	NO_2	+	H_2O
10	H_3PO_4	+	NaOH	→	NaH_2PO_4	+	H_2O		
11	H_3PO_4	+	NaOH	→	Na_3PO_4	+	H_2O		
12	H_3PO_4	+	NaOH	→	Na_2HPO_4	+	H_2O		