CELS Resource

Chemical Formula

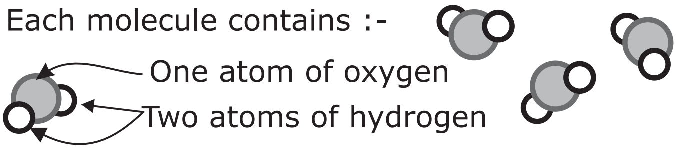
Aims

- To write formulae for simple molecules
- To distinguish between prefixes and suffixes in

Many substances are made by joining together a small group of atoms to form a **molecule** for example water.

The **formula** for water **H_2O** shows which atoms and how many of each are used to make one molecule.

Each molecule contains :-

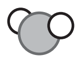
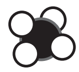
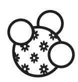
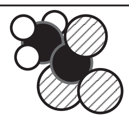
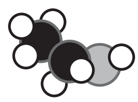
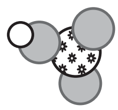
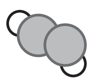


Task: Why should we actually write **H_2O_1** ?

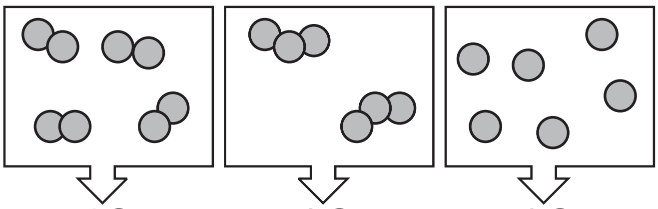
It is quite common to leave the number '1' out of a chemical formula.
Task: For the next task you should include it. Use the key to work out the formula for each substances shown below.

Key

O	Oxygen
C	Carbon
H	Hydrogen
Cl	Chlorine
N	Nitrogen

	Water **H_2O**		Methane **C_1H_4**
	Hydrochloric acid 		Ammonia
	Trichloroethane 		Alcohol (ethanol)
	Nitric acid 		Hydrogen peroxide

There is an important difference when numbers are used either in-front-of or after a chemical symbol. Look at the following pictures using oxygen atoms:



$4O_2$ $2O_3$ $6O$

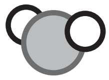
Task: In your own words describe the difference between the numbers in front (prefix) and numbers which go after (suffix) the symbol for oxygen.
Try to use the terms **molecule** and **atom** carefully.

Chemical Formula

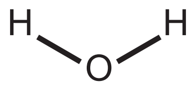
> **Aims**
> To write formulae for simple molecules
>
> To convert molecular formulae into structures

To show that different substances are joined together we can use either pictures of atoms or symbols.

Water can be drawn using circles as atoms

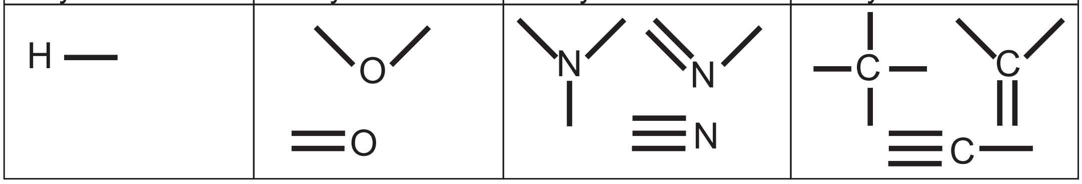


It can also be draw as **stick structures** showing how the atoms are joined.

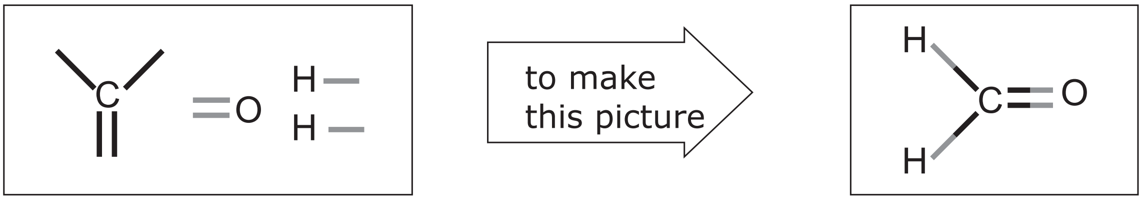


When drawing stick structures there are rules to control the number of links (bonds) an atom can have. These are shown below.

Hydrogen only 1 link	**Oxygen** always 2 links	**Nitrogen** always 3 links	**Carbon** always 4 links



To draw out $C_1H_2O_1$, take the pictures below

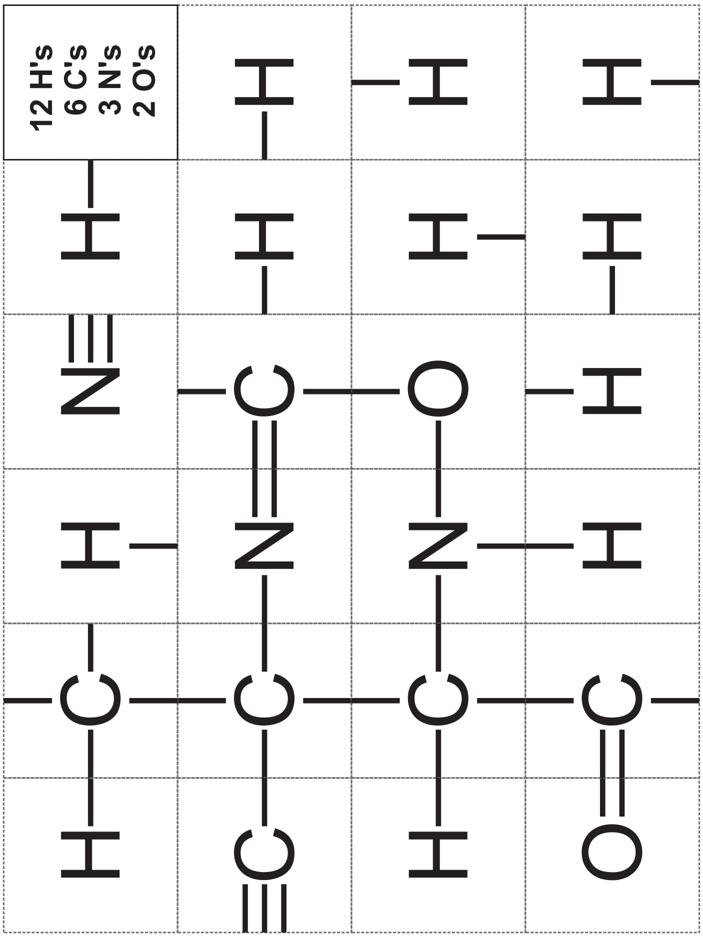


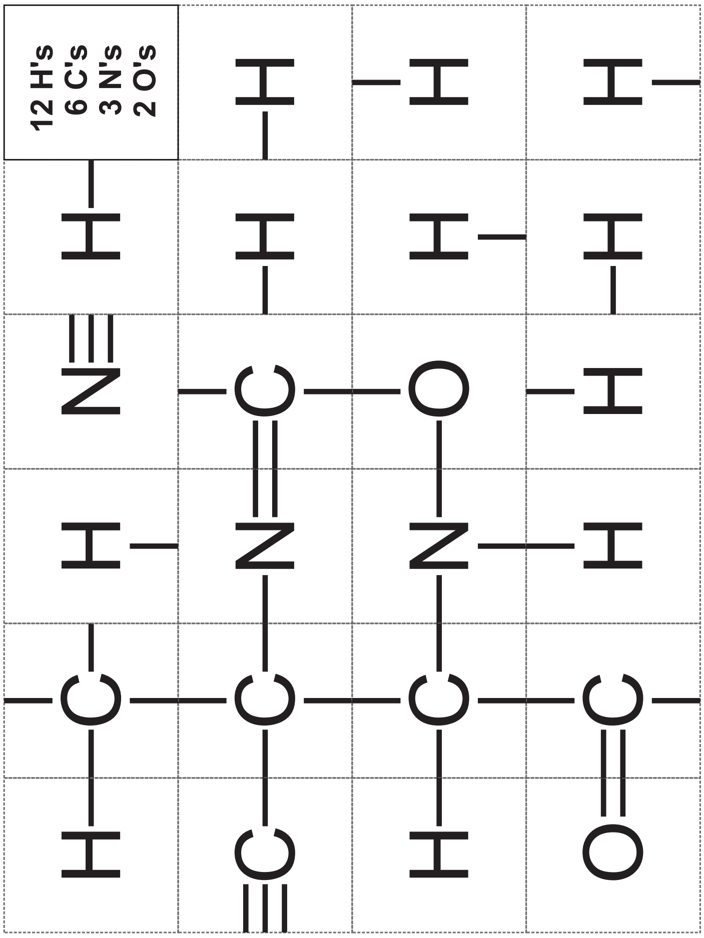
Task Use the 'rules' above and draw out the following molecules

C_1H_4 | C_2H_6 | $C_1H_4O_1$

N_1H_3 | $C_1N_1H_5$ | C_3H_8

$C_2H_6O_1$ | C_2H_4 | $H_1C_1N_1$


12 H's
6 C's
3 N's
2 O's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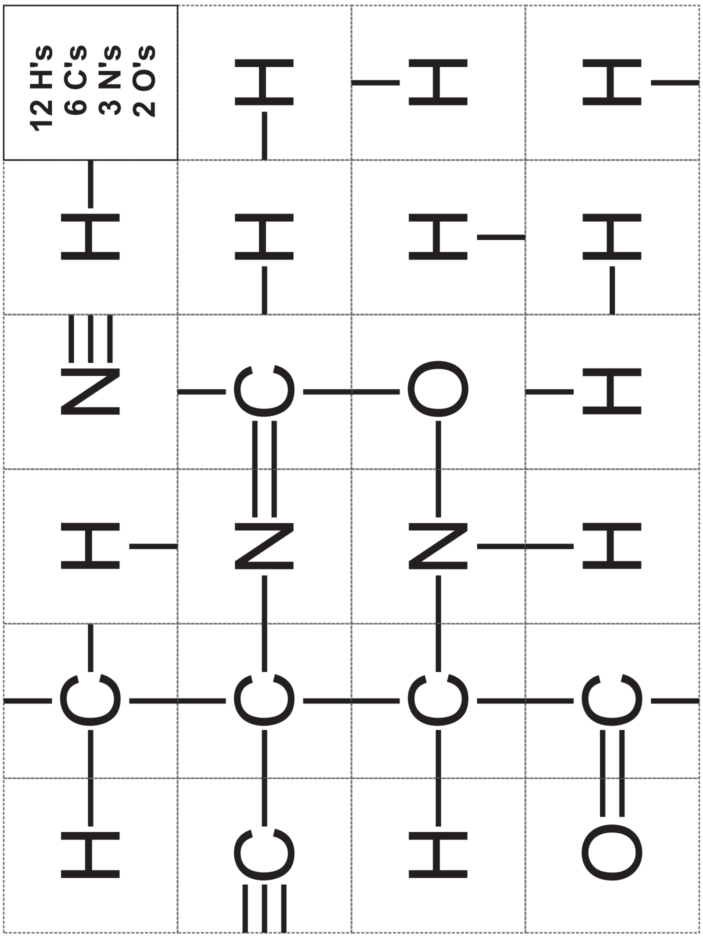
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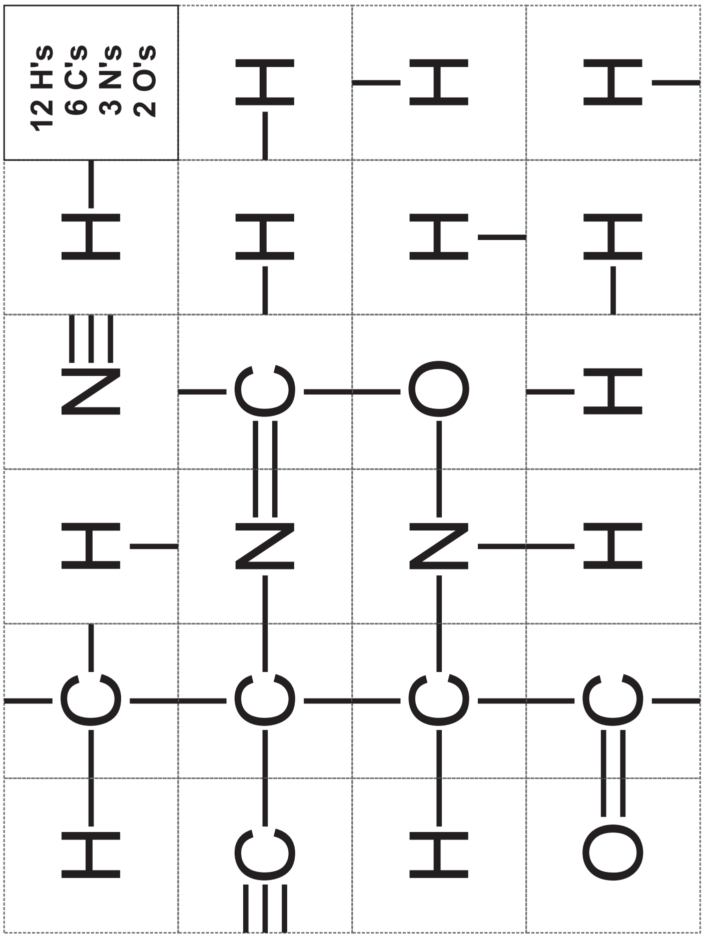
12 H's
6 C's
3 N's
2 O's

Chemical Formula

Aims

To write formulae for ionic compounds

To apply rules for formula writing to complex examples

Some substances are made up from charged particles called **ions**. These are found inside **ionic compounds**. When ions are joined together to make ionic compounds the total combination of **+**ve and -ve ions is **neutral**

Aluminium chloride is made up of positive aluminium ions (Al^{+++}) and negative chloride ions (Cl^{-}) These ions can also be written as Al^{3+} and Cl^{1-}.

If one aluminium Al^{3+} joins with three chlorides Cl^{1-} Cl^{1-} Cl^{1-} because this gives **+++** and **- - -** the combination would be **neutral.** This is written as $\mathbf{Al_1Cl_3}$ to show how many of each ion is needed.

For the following questions, write down the symbol for each part of the name and then balance the ions so that the total number or + and - charges are balanced. Finally work out the formula for each compound.

a)	Zinc bromide	=	Zn^{2+} Br^{1-} Br^{1-}	=	Zn_1Br_2	or simplified $ZnBr_2$
b)	Magnesium chloride	=		=		
c)	Sodium chloride	=		=		
d)	Copper(II) oxide	=		=		
e)	Iron(III) oxide	=		=		
f)	Iron(II) sulphide	=		=		
g)	Aluminium bromide	=		=		
h)	Sodium oxide	=		=		
i)	Aluminium sulphide	=		=		

Complex examples - ions like carbonate ions already contain a number of joined atoms. To avoid confusion we often use brackets - see the two examples below.

a)	Aluminium hydroxide	=	Al^{3+} OH^{1-} OH^{1-} OH^{1-}	=	**not** $AlOH_3$ **but** $Al(OH)_3$
a)	Ammonium carbonate	=	NH_4^{1+} NH_4^{1+} CO_3^{2-}	=	**not** $NH_{42}CO_3$ **but** $(NH_4)_2CO_3$
b)	Magnesium hydroxide	=		=	
c)	Ammonium sulph**ide**	=		=	
d)	Calcium nitrate	=		=	

Positive ions

Aluminium	Al^{3+}	Lead	Pb^{2+}
Ammonium	NH_4^{1+}	Lithium	Li^{1+}
Barium	Ba^{2+}	Magnesium	Mg^{2+}
Calcium	Ca^{2+}	Potassium	K^{1+}
Copper	Cu^{2+}	Silver	Ag^{1+}
Hydrogen	H^{1+}	Sodium	Na^{1+}
Iron(II)	Fe^{2+}	Zinc	Zn^{2+}
Iron(III)	Fe^{3+}		

Negative ions

Bromide	Br^{1-}	Nitrate	NO_3^{1-}
Carbonate	CO_3^{2-}	Oxide	O^{2-}
Chloride	Cl^{1-}	Sulph**ate**	SO_4^{2-}
Fluoride	F^{1-}	Sulph**ide**	S^{2-}
Hydroxide	OH^{1-}		
Iodide	I^{1-}		

Word Equations

Aims

To construct word equations from supplied symbols

To construct word equations from descriptions of reactions

Chemical reactions can be represented with either words or with symbols and formulae.

Often when chemical symbols are used, an important addition is the use of **(s)**, **(l)**, **(g)** and **(aq)** just after each of the formulae. Using these **state symbols** can make subtle differences :

H_2O (g)	= Steam	NaCl (s)	= Solid salt
H_2O (s)	= Ice	NaCl (aq)	= Salt water

The **state symbols**, therefore, mean :(s) = (l) = (g) =
The state symbol (aq) is often misinterpreted. It is used when a chemical is dissolved in water or used to represent a dilute acid - diluted with water - (aq) means **aqueous**.

Task

On lined paper convert each of the following symbols into complete **word equations**.

Eg	NaCl (aq) sodium chloride solution	+	$AgNO_3$ (aq) silver nitrate solution	=>	$NaNO_3$ (aq) sodium nitrate solution	+	AgCl (s) silver chloride solid
(1)	Mg (s)	+	H_2SO_4 (aq) sulphuric acid	=>	$MgSO_4$ (aq)	+	H_2 (g)
(2)	Mg (s)	+	H_2O (g)	=>	MgO (s)	+	H_2 (g)
(3)	Ca (s)	+	H_2O (l)	=>	$Ca(OH)_2$ (aq)		+H_2 (g)
(4)	CH_4 (g) Methane gas	+	2 O_2 (g)	=>	CO_2 (g)	+	2 H_2O (g)

Carefully read through the following descriptions and construct **word equations**.

A block of **carbon** burns in pure **oxygen** to give only one product, **carbon dioxide** gas.

Task

Word equation = **Carbon + Oxygen => Carbon dioxide**

(5) Water is the only product from the reaction between hydrogen and oxygen.

(6) Dilute hydrochloric acid reacts with magnesium *solid*. One of the products is a *solution* of magnesium chloride. The second product is a colourless gas which 'pops' when tested with a lighted splint.

(7) Calcium oxide is made by heating up calcium carbonate. A second product is a gas which turns limewater cloudy.

(8) If magnesium is added to copper sulphate solution, one of the products is a brown metal.

(9) Calcium carbonate gives carbon dioxide, a sulphate and water when added to a beaker containing dilute sulphuric acid.

(10) Liquid magnesium oxide can be decomposed by electricity into magnesium and oxygen.

Word Equations

Aims: To construct word equations from descriptions of reactions

Chemical reactions can be represented with either words or with symbols and formulae.

Carefully read through the following descriptions and construct **word equations**.

eg A block of carbon burns in pure oxygen to give only one product, carbon dioxide gas.

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(5) Calcium carbonate gives carbon dioxide, calcium sulphate and water when added to a beaker containing dilute sulphuric acid.

(6) Liquid magnesium oxide can be broken up by electricity into magnesium and oxygen.

(7) When sodium is added to water it floats on the surface and fizzes. The gas made is explosive. The sodium also turns the water into an alkali called sodium hydroxide.

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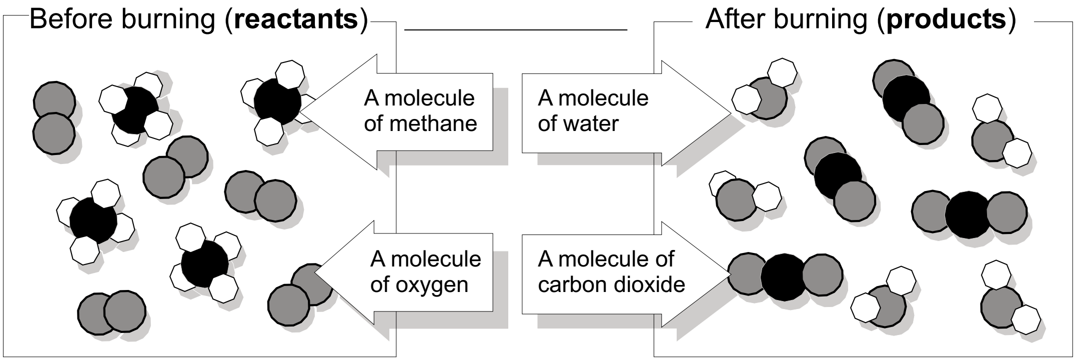
Balanced Symbol Equations

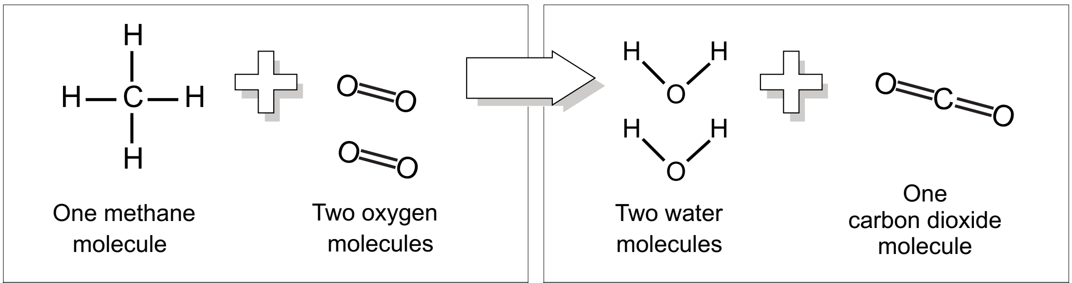
Aims	
CQ1d HF	To recognise number of atoms in reactants must be balanced by those in products
	To create a balanced equation from supplied information

When methane (natural gas) burns in air, oxygen turns the fuel into carbon dioxide and water.

The following pictures show this happening



These pictures can be simplified using stick diagrams and by using as few molecules as possible.



Task

Work out the starting number of			Work out the finishing number of		
Carbon atoms =	Hydrogen atoms =	Oxygen atoms =	Carbon atoms =	Hydrogen atoms =	Oxygen atoms =

Another way to represent the burning of methane is to use the following **symbol equation**

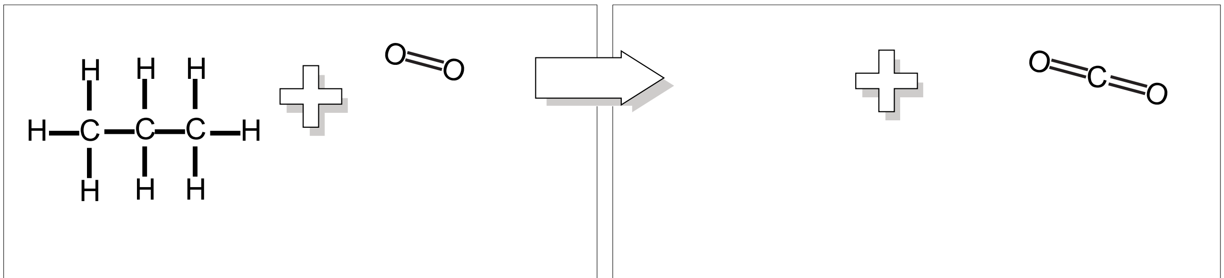
CH_4	+	$2O_2$	=>	$2H_2O$	+	CO_2
methane		oxygen		water		carbon dioxide

Task

Using your answers to the task above, say why this is called a **balanced** chemical equation:

Task

Another fuel which can be burned in a similar way is propane (camping gas). **Complete** the following boxes and symbols to create a balanced equation.



C_3H_8	$5\ O_2$	$4\ H_2O$	

Balanced Symbol Equations

Aims: To complete and balance supplied chemical equations

Balance the following equations be inserting numbers **in front** or by filling in the missing chemical formula.

Oxidation Reactions

Na	+	O_2	=>	Na_2O		
Mg	+	O_2	=>	MgO		
	+	**2** O_2	=>	CO_2	+	**2** H_2O
C_2H_4	+	O_2	=>	CO_2	+	H_2O
C_6H_{12}	+	O_2	=>	CO_2	+	H_2O
C_6H_{12}	+	O_2	=>	**CO** (carbon monoxide)	+	H_2O
C_6H_{14}	+	O_2	=>	CO_2	+	H_2O

Decomposition Reactions

$NaHCO_3$	=== heat ====>	Na_2CO_3	+	H_2O	+	CO_2
2 $NaNO_3$	=== heat ====>	**2** $NaNO_2$	+			
$CuCO_3$	=== heat ====>	CuO	+			
$NaCl$	= electrolysis =>	Na	+	Cl_2		
Al_2O_3	= electrolysis =>	Al	+	O_2		
ZnO	= electrolysis =>	Zn	+	O_2		

Neutralisation Reactions

H_2SO_4	+	$Ca(OH)_2$	=>	$CaSO_4$	+	H_2O		
HCl	+	Na_2CO_3	=>	$NaCl$	+	H_2O	+	CO_2
HCl	+	$NaOH$	=>		+	H_2O		
HCl	+	$Ca(OH)_2$	=>	$CaCl_2$	+	H_2O		

Redox Reactions

Fe_2O_3	+	H_2	=>	Fe	+	H_2O		
CuO	+	CH_4	=>	Cu	+	CO_2	+	H_2O
Cu	+	NO	=>	CuO	+	N_2		
	+	**3** CO	=>	**2** Fe	+	**3** CO_2		

Aims

To convert symbol equations into word equations

Higher : To balance equations

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Word and Symbol Equations

Task

Complete each box by adding the name of each substance.

Reactant		Reactant		Product		Product		Product
H_2	+	Cl_2	→	_HCl Hydrogen chloride				
_Fe	+	O_2	→	_FeO				
Zn	+	Cl_2	→	$ZnCl_2$				
CH_4 Methane	+	_O_2	→	CO_2	+	_H_2O		
GeH_4 Germanium hydride	+	_O_2	→	GeO_2	+	_H_2O		
$Mg(OH)_2$ Magnesium hydroxide	+	_HNO_3 Nitric acid	→	$Mg(NO_3)_2$	+	_H_2O		
_NH_3 Ammonia	+	_CuO	→	_Cu	+	_H_2O	+	N_2
$CuCO_3$ Copper carbonate	+	_HCl Hydrochloric acid	→	$CuCl_2$	+	H_2O	+	CO_2

The chemicals on this side of the equation are called the **reactants** because

The chemicals on this side of the equation are called the **products** because

Task

Six of the equations can either be described as neutralisation, combustion or redox. Shade in the arrows in the middle of each equation according to the following key

Green = Neutralisation **Red** = Combustion (oxidation) **Blue** = Redox

Task

Higher only Make sure each equation is fully balanced.

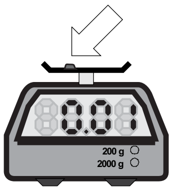
Chemical Masses

Aims
CQ2a HF

To know that atoms are measured on a relative scale (RAMs)

To use RAMs to calculate formula masses (RMMs)

Atoms are incredibly small particles.
It takes **30,500,000,000,000,000,000** gold atoms to show up as **0.01** grams on a top pan balance



Atoms are very light indeed!

One atom of hydrogen has a mass of 0.00000000000000000000000166 g (= 1.66×10^{-24} g).

To avoid using such ridiculously small numbers in grams, chemists use an alternative scale called the **Relative Atomic Mass** scale. On this scale one atom of carbon is said to have a mass of 12 no units. All other atoms are compared with carbon.

Task

Magnesium atoms are **twice** as heavy as carbon atoms, so chemists say that they have a **relative mass** of ___no units.

Task

Three helium atoms would have the same mass as one carbon atom. On the relative atomic mass scale one helium has a mass of ___no units.

Here is a small table of important Relative Atomic Masses (**RAMs**)

H 1 Hydrogen	**Li** 7 Lithium	**C** 12 Carbon	**N** 14 Nitrogen	**O** 16 Oxygen	**F** 19 Fluorine	**Na** 23 Sodium	**Mg** 24 Magnesium
Al 27 Aluminium	**Si** 28 Silicon	**S** 32 Sulphur	**Cl** 35.5 Chlorine	**K** 39 Potassium	**Ca** 40 Calcium	**Fe** 56 Iron	**Cu** 64 Copper

Formula Masses

Carbon dioxide, CO_2 , has one carbon atom and two oxygen atoms and a mass = 12 + 16 + 16 = 44
This is known as its relative formula (molecular) mass or **RMM**.

Task

Calculate the formula mass for each of the substances which follow:.

Magnesium oxide	MgO	=	Copper oxide	CuO	=
Sodium oxide	Na_2O	=	Aluminium oxide	Al_2O_3	=
Iron(III) oxide	Fe_2O_3	=	Sulphur dioxide	SO_2	=
Silica	SiO_2	=	Sodium hydroxide	$NaOH$	=
Copper sulphate	$CuSO_4$	=	Lithium nitrate	$LiNO_3$	=
Nitric acid	HNO_3	=	Sulphuric acid	H_2SO_4	=
Ethanol	C_2H_6O	=	Butane	C_4H_{10}	=
TNT	$C_7H_5N_3O_6$	=	Glucose	$C_6H_{12}O_6$	=

Calcium hydroxide, $Ca(OH)_2$, contains Ca, OH and a second OH.
To calculate the formula mass of calcium hydroxide = 40 + **(**16+1**)** + **(**16+1**)** = 74.

Task

Iron(III) hydroxide	$Fe(OH)_3$	=	Copper nitrate	$Cu(NO_3)_2$	=
Ammonium sulphate	$(NH_4)_2SO_4$	=	Magnesium hydroxide	$Mg(OH)_2$	=

The masses for the following compounds have already been calculated. The compounds include elements whose masses are not given above. Work out the mass for the element in **bold** print.

Task

Zinc oxide	**Zn**O = 81	Zinc	=
Phosphorus trifluoride	**P**F_3 = 88	Phosphours	=
Caesium chloride	**Cs**Cl = 168.5	Caesium	=
Sodium iodate(V)	Na**I**O_3= 198	Iodine	=

Chemical Masses

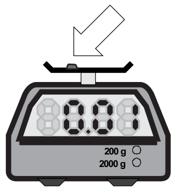
Aims

CQ2a F

To know that atoms are measured on a relative scale (RAMs)

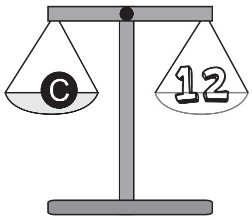
To use RAMs to calculate formula masses (RMMs)

Atoms are incredibly small particles.
It takes **30,500,000,000,000,000,000** gold atoms just to show up as **0.01** grams on a top pan balance



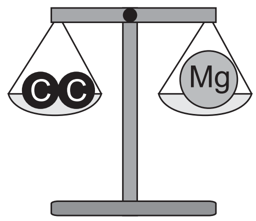
Atoms are <u>very</u> light indeed!

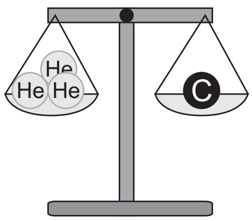
To help scientists an alternative weighing scales called the **Relative Atomic Mass** scale are used.



On this scale <u>one atom</u> of **carbon** is said to have a mass of 12 no units.
Scientists then compare other atoms against carbon.

Magnesium atoms are **twice** as heavy as carbon atoms, so scientists say that magnesium weighs ____no units.





Three helium atoms would have the same mass as one carbon atom. On the relative atomic mass scale one helium atom would weigh ____no units.

Here is a small table of the masses of other atoms (**RAMs**)

H 1 Hydrogen	**Li** 7 Lithium	**C** 12 Carbon	**N** 14 Nitrogen	**O** 16 Oxygen	**F** 19 Fluorine	**Na** 23 Sodium	**Mg** 24 Magnesium
Al 27 Aluminium	**Si** 28 Silicon	**S** 32 Sulphur	**Cl** 35.5 Chlorine	**K** 39 Potassium	**Ca** 40 Calcium	**Fe** 56 Iron	**Cu** 64 Copper

Formula Masses

Carbon dioxide, CO_2 , is made by joining = carbon + oxygen + oxygen
Using the numbers in the table above = 12 + 16 + 16
= 44

This is known as its relative molecular mass or **RMM**. It tells us how heavy one molecule is.

Task

Calculate the mass for each of the substances which follow:.

Magnesium oxide	MgO	=	Copper oxide	CuO	=
Sodium oxide	Na_2O	=	Sodium hydroxide	$NaOH$	=
Sand	SiO_2	=	Sulphur dioxide	SO_2	=
Ammonia	NH_3	=	Methane	CH_4	=
Rust	Fe_2O_3	=	Aluminium oxide	Al_2O_3	=
Ethanol	C_2H_6O	=	Butane	C_4H_{10}	=

Using Formula Masses

Aims	To relate RAMs and RMMs to quantities involved in reactions
CQ3a HF	To collect and interpret masses from experimental data

Once a chemist has worked out a formula mass (RMM) they can use it to start to make predictions about reactions.

When green **copper carbonate** is heated strongly, it breaks up into black **copper oxide** and **carbon dioxide** which escapes into the atmosphere.

Reactant $CuCO_3$ (s) => CuO (s) + CO_2 (g) **Products**

Formula masses =

Task: Work out and write down the formula mass underneath each of the substances above.

From your formula calculations, you should see that copper carbonate does not split into two equal parts (by mass). Circle the combination which you think best describes the 'split'.

Task: 100% => 50:50 60:40 70:30 80:20 90:10

Now calculate the actual percentage of copper oxide as shown opposite and then complete the following.

$$\frac{\textbf{mass of CuO}}{\textbf{mass of CuCO}_3} \times 100$$

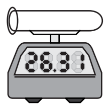
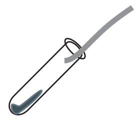
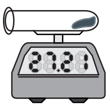
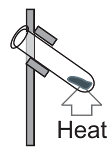
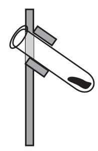
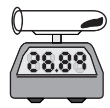
Task

Prediction

When copper carbonate is heated, it breaks up to form a gas which escapes and a solid. The solid, copper oxide, should weigh about ____ % of the original solid.

Task / Exp / Goggles

Method You must wear goggles at all times

					
Measure the mass of an empty boiling tube	Add 1 spatula of powdered copper carbonate	Reweigh the tube and starting material	Clamp and then **gently** heat the tube.	If no further change takes place allow the tube to cool.	Reweigh the cool tube.

Task

Results complete the following calculations

① Mass of empty boiling tube		=		g
② Mass of boiling tube + green carbonate		=		g
③ Mass of boiling tube + black oxide		=		g
Mass of carbonate used	= ②-①	=		g
Mass of oxide produced	= ③-①	=		g

Percentage

$$\frac{\textbf{mass of oxide}}{\textbf{mass of carbonate}} \times 100$$

Task

Conclusion

From my prediction I expected that the solid product would weigh ___ % of the starting solid.
From my practical I found that the percentage was ___ %

Your values should be close; with greater accuracy and more time it is possible to reach the predicted percentage

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Using Formula Masses

Aims CQ3a F	To relate RAMs and RMMs to quantities involved in reactions To collect and interpret masses from experimental data

When chemists carry out experiments to make new materials they need to use the right 'recipe'. It is important that they can predict how much to use and how much product will be made.

Experiment

When **magnesium carbonate** is heated strongly, it breaks up into **magnesium oxide** and **carbon dioxide** which escapes into the atmosphere.

Task: Using Mg=24, C=12 and O=16 and the equation below, work out the masses of chemicals involved in this experiment.

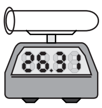
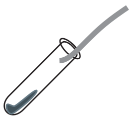
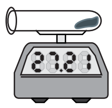
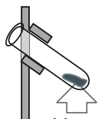
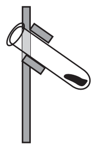
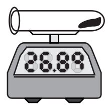
$$MgCO_3\ (s) \Rightarrow MgO\ (s) + CO_2\ (g)$$

Reactant | **Products**

Predicted masses = ______g ______g ______g

Your calculation should show that magnesium carbonate breaks up almost **50:50** with half escaping as a gas. You will now carry out an experiment to see if this is true

Method You must wear goggles at all times

			 Heat		
Measure the mass of an empty boiling tube	Add 1 spatula of powdered magnesium carbonate	Reweigh the tube and starting material	Clamp and then **gently** heat the tube.	Heat for 5 minutes or until no further change seen	Reweigh the cool tube.

Results complete the following calculations

① Mass of empty boiling tube = g
② Mass of boiling tube + white carbonate = g
③ Mass of boiling tube + heated powder = g

Mass of carbonate used = ②-① = g
Mass of oxide produced = ③-① = g

Conclusion

You calculated that about half of the heated powder breaks off as a gas. Explain if your results prove this or not.

Using Percentages

Aims
CQ3b H

To calculate percentage compositions

To identify substances from percentage compositions

The percentage of solid left after decomposing a substance with a bunsen burner can be easily calculated. This can be useful in identifying substances.

A mineral was thought to be either calcium carbonate (**$CaCO_3$**) or magnesium carbonate (**$MgCO_3$**). A small sample was taken and strongly heated to decompose it

$\underline{X}CO_3$ (s) + heat => $\underline{X}O$ (s) + CO_2 (g)   where $\underline{X}$ could be either Ca or Mg

Percentage

$$\frac{\textbf{RMM of oxide}}{\textbf{RMM of carbonate}} \times 100$$

The solid left was found to weigh 48% of the starting mineral.

Task

Use the equation opposite to suggest which mineral was involved (Ca=40, Mg=24, C=12, O=16)

Percentage Compositions

Ethane has the formula, C_2H_6 ; ethane contains two atoms of carbon and six atoms of hydrogen

The relative molecular mass (formula mass) of Ethane = (12 × 2) + (6 × 1)
= 30

The fraction, by mass, of carbon in Ethane = 24 out of 30
= 24/30 × 100%
= 80.0 %

1) Calculate the percentage by mass of carbon in the following molecules (C=12, H=1, O=16)

(a) Methane CH_4 (b) Ethene C_2H_4 (c) Butane C_4H_{10} (d) Ethanol C_2H_6O (e) Methanol CH_4O

2) Calculate the percentage by mass of nitrogen in the following fertilizers (N=14, S=32)

(a) Ammonium nitrate NH_4NO_3 (b) Ammonium sulphate $(NH_4)_2SO_4$ (c) Ammonium hydroxide NH_4OH

3) Iron (Fe=56) reacts with oxygen to form three possible products, iron (II) oxide **FeO,** iron(III) oxide **Fe_2O_3** and mixed iron oxide **Fe_3O_4**

(a) Calculate the percentage of oxygen by mass in each of the three oxides

(b) In one particular experiment, 2.24 grams of iron filings were burnt in pure oxygen.
A red product was produced and had a mass of 3.20 grams.
Calculate the mass of oxygen which joined with 2.24 grams of iron.

(c) From your answer to part (b),
Calculate the percentage by mass of oxygen in the 3.20 grams of iron oxide.

(d) From your answers to parts (a) and (c),
Suggest which of the three possible oxides was prepared in the experiment.

(c) Consider the formula given for each of the iron oxides and suggest a reason why Fe_3O_4 is called ***mixed*** iron oxide

Chemical Percentages

Aims: To calculate percentage compositions

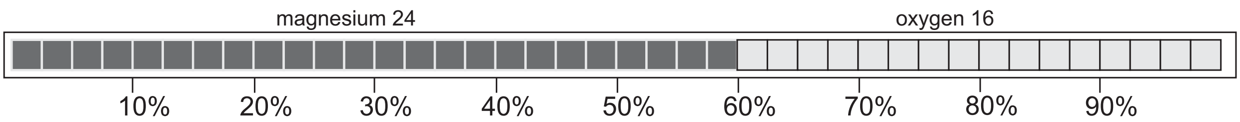
CQ3b F

Sometimes it is useful to talk about how a chemical using percentages. For example 24 carat gold is 100% pure but 12 carat only contains half as much gold.

When we calculate percentages for a substance we start by looking at their masses.

Magnesium oxide = MgO = 24 + 16 = **40**

The following **40 boxes** show these masses of magnesium (24) and oxygen (16)



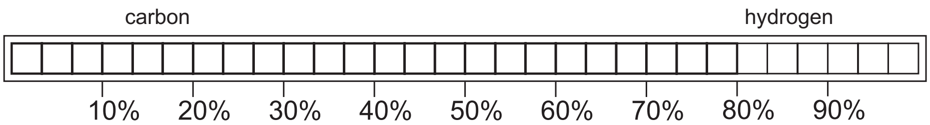
Using this chart, it is easy to see that 60% of the chemical is made up of magnesium.

Calculating Percentages

Ethane has the formula, C_2H_6 ; ethane contains two atoms of carbon and six atoms of hydrogen

The relative mass of Ethane = C + C + H + H + H + H + H + H
= **12** + **12** + **1** + **1** + **1** + **1** + **1** + **1**
= **30**

Using **30 boxes**



Task: Colour in the chart above using ***blue*** for carbon and ***red*** for hydrogen

What is the percentage of **carbon** in the chemical ethane ?

Instead of using boxes it is often quicker to use a calculator to work out percentages
Propane has the formula, C_3H_8 ; it contains three atoms of carbon and eight atoms of hydrogen

The relative mass of Propane = C + C + C + H + H + H + H + H + H + H + H
= **12** + **12** + **12** + **1** + **1** + **1** + **1** + **1** + **1** + **1** + **1**
= **44**

The mass of just carbon in Propane = **36**

Now that we have these two numbers
we can calculate the percentage of carbon=>

$$\frac{\text{just carbon}}{\text{whole mass}} \times 100\% = \frac{36 \times 100}{44} = 82\%$$

Task: Calculate the percentage by mass of carbon in the following molecules (C=12, H=1, O=16)

(a) Methane CH_4 (b) Ethene C_2H_4 (c) Butane C_4H_{10} (d) Ethanol C_2H_6O (e) Methanol CH_4O

Empirical Formulae

Aims

To calculate empirical formulae

To calculate empirical formulae from percentage compositions

CQ3c H

Sometimes chemical formula can be simplified. This leads to its **empirical formula**.

Ethene has the formula, C_2H_4.

The ratio of carbon : hydrogen in one molecule of ethene = 2 : 4
The ratio of carbon : hydrogen in ethene can be simplified = 1 : 2

Ethene can also be simplified into an empirical formula = C_1H_2
= CH_2

Benzene has the formula, C_6H_6.

The ratio of carbon : hydrogen in one molecule of benzene = 6 : 6
= 1 : 1

The empirical formula of benzene is therefore = C_1H_1
= CH

Task

Answer the following questions on **lined paper.**

1) Work out the empirical formula for the following molecules

(a) Propene C_3H_6 (b) Ethane C_2H_6 (c) Butane C_4H_{10} (d) Butene C_4H_8 (e) Propane C_3H_8

2) Ethane has the molecular formula C_2H_6 and the empirical formula CH_3

(a) Calculate the percentage by mass of carbon in the molecular formula C_2H_6

(b) Calculate the percentage by mass of carbon in the empirical formula CH_3

(c) Comment on the %carbon in the molecular and empirical formulae.

3) A molecule has 75% carbon and 25% hydrogen by mass. If we use these numbers as follows

75% Carbon → divide by C=**12** → **6.25**

25% Hydrogen → divide by H=**1** → **25**

This gives us the formula as $\mathbf{C_{6.25}H_{25}}$ which simplifies into the <u>empirical formula</u> $\mathbf{C_1H_4}$

(a) Work out the empirical formula for the hydrocarbon compound containing 85.7% carbon and 14.3% hydrogen.

(b) Work out the empirical formula for the hydrocarbon compound containing 81.8% carbon and 18.1% hydrogen. (Hint the molecule has an RMM of 44)

(c) Work out the empirical formular for a compound with 60% magnesium and 40% oxygen given that the relative atomic mass of Mg=24 and O=16

Chemical Masses 1

Aims CQ4a H	To calculate RMMs and convert these into molar quantities To calculate molar quantities for provided balanced equations

Knowing how to calculate how much molecules weigh can help us to easily predict the amounts of chemicals needed for a successful reaction

For example it is possible to predict the mass of oxygen needed to completely burn methane gas:

	reactants			products	
Symbol equation	CH_4 +	**2** O_2	=>	CO_2 +	**2** H_2O
Atomic masses no units	12 + (4 × 1) = 16	**2** × (16 + 16) = 64		12 + 16 + 16 = 44	**2** × (1 + 1 + 16) = 36
Lab or **Molar quantity**	16 g	64 g		44 g	36 g

Formula masses have no units; remember they are base on a relative scale where one atom of carbon = 12. But we can easily stick **'grams'** after the numbers we calculate; chemists refer to these amounts as the **molar quantities** for the equation. These amounts involve trillions of atoms (what are known as moles of atoms).

Using your previous sheets to find the relative atomic masses, calculate the mass of each of the substances in the following equations:

Symbol equation	C_2H_4	+	3 O_2	=>	2 CO_2	+	2 H_2O
Atomic masses	24 + 4		3 × (16 + 16)		2 × (12 + 16 + 16)		2 × (1 + 1 + 16)
Molar quantities							

Symbol equation	2 NaOH	+	H_2SO_4	=>	Na_2SO_4	+	2 H_2O
Atomic masses							
Molar quantities							

Symbol equation	2 Na	+	2 H_2O	=>	2 NaOH	+	H_2
Atomic masses							
Molar quantities							

Symbol equation	Mg	+	2 H_2O	=>	$Mg(OH)_2$	+	H_2
Atomic masses							
Molar quantities							

Symbol equation	2 Al_2O_3	=>	4 Al	+	3 O_2
Atomic masses					
Molar quantities					

Symbol equation	2 KNO_3	=>	2 KNO_2	+	O_2
Atomic masses					
Molar quantities					

Symbol equation	N_2	+	3 H_2	=>	2 NH_3
Atomic masses					
Molar quantities					

Chemical Masses 2

Aims
CQ4b H
To calculate RMMs and convert these into molar quantities

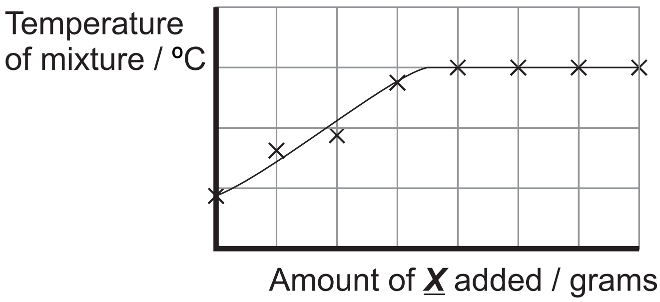
To calculate molar quantities for provided balanced equations

When a more reactive metal is added to copper sulphate, the copper is **displaced.** Displacement reactions are often **exothermic** (releasing heat). The greater the amount of chemicals used, the more energy will be released.

In the following equation metal ***X*** is higher up in the reactivity series than copper.

$$X\ (s) \quad + \quad CuSO_4\ (aq) \quad => \quad XSO_4\ (aq) \quad + \quad Cu\ (s)$$

Starting with a small beaker of copper sulphate one spatula at a time, of metal ***X***, is added and carefully stirred. If the temperature is measured each time the following graph should be obtained.



Task

Shade in the part of the graph where more than enough (excess) metal has been added

The graph shows that for the experiment there is correct or **optimum** amount of metal ***X*** to use; this can be used to help identify the metal.

Aim To identify metal X by scaling experiment results up to molar quantities

Method You must wear goggles at all times

Task / Exp / Goggles

1. Measure out 25 cm³ of 0.5M copper sulphate solution into a boiling tube
2. Record the initial temperature.
3. Measure out 0.20g** of metal ***X***.
4. Pour all of ***X*** into the boiling tube.
5. Swirl and carefully measure the maximum temperature reached.
6. Repeat with 0.40, 0.60, ... 1.40g of metal ***X***

You could be asked to collate your results as a whole class and will be given a different mass of ***X*.

Calculation
Using the axis given in the example diagram, plot the determine the optimum mass of metal ***X***

25cm³ of 0.5M copper sulphate contains 2.0g of copper sulphate. If you had used a molar quantity, you would have used 160g. Use the following to help you scale up your results to molar quantities.

Task

$$X\ (s) \quad + \quad CuSO_4\ (aq) \quad => \quad XSO_4\ (aq) \quad + \quad Cu\ (s)$$

	X (s)	CuSO4 (aq)
Experiment quantities	g	**2.00** g
	Scaled up	Scaled up x 80
Molar quantity	g	**160** g

This should give you the RAM of the unknown metal. From a periodic table you should be able to identify ***X***.

Chemical Masses

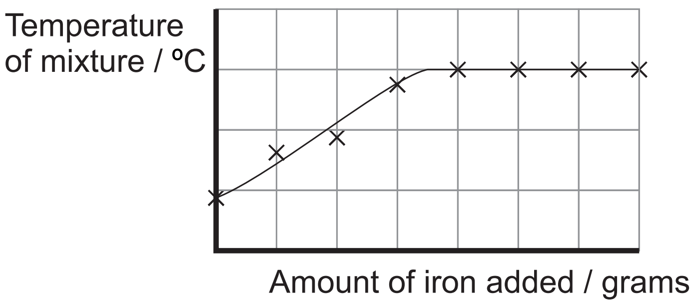
Aims
CQ4b HF
- To calculate RMMs and convert these into molar quantities
- To calculate molar quantities for provided balanced equations

When a more reactive metal is added to copper sulphate, the copper is **displaced.** Displacement reactions are often **exothermic** (releasing heat). The greater the amount of chemicals used, the more energy will be released.

Iron is higher up in the reactivity series than copper. It reacts as follows.

$$Fe_{(s)} + CuSO_{4\,(aq)} \Rightarrow FeSO_{4\,(aq)} + Cu_{(s)}$$

When iron, one spatula at a time, is added and stirred with copper sulphate the temperature slowly rises. The following graph should be obtained after several spatulas.



Task — Circle the graph where the enough iron has been added to give a full reaction.

The graph shows that for the experiment there is correct or **optimum** amount of iron to use;

Aim To determine the correct amount of iron needed to react with 2g of copper sulphate

Method You must wear goggles at all times

1. Measure out 25 cm³ of 0.5M copper sulphate solution (2g) into a boiling tube
2. Record the initial temperature.
3. Measure out 0.20g** of iron filings
4. Pour all of the iron into the boiling tube.
5. Swirl and carefully measure the maximum temperature reached.
6. Repeat with 0.40, 0.60, ... 1.40g of iron.

**You could be asked to collate your results as a whole class and will be given a different mass of iron.

Calculation
Using the axis given in the example diagram, plot and then determine the required mass of iron.

Chemical recipe books give the 'perfect' quantities as **160g** of copper sulphate with **56 g** of iron. The 25cm³ of solution you used contained only 2.0g of copper sulphate (a scaled down experiment).

Task

	$Fe_{(s)}$	+	$CuSO_{4\,(aq)}$
Perfect quantity	**56** g		**160** g
	Scaled down		Scaled down ÷ 80
Predicted quantities	g		**2.00** g

Use this equation to help you work out how much iron (in theory) you needed to add.

How does this compare to your actual experiment ?

Using The Right Mass

Aims
CQ4b F

To calculate RMMs and convert these into molar quantities

To calculate molar quantities for provided balanced equations

We can use (atomic) masses to work out the right amounts to use for a chemical reaction.

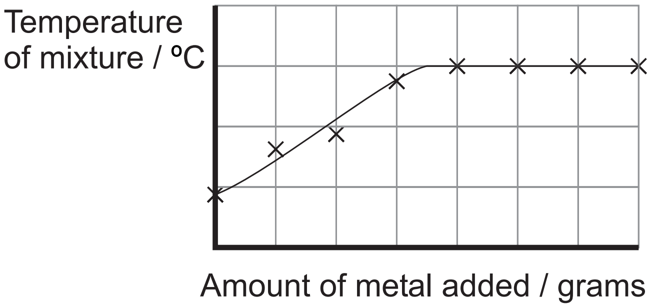
During reactions there are often signs that the right amounts have been used.

Experiment

Iron reacts with copper sulphate to make   and

$$Fe\ (s) \quad + \quad CuSO_4\ (aq) \quad => \quad FeSO_4\ (aq) \quad + \quad Cu\ (s)$$

If spatula at a time of iron is added to a small beaker of copper sulphate the temperature slowly rises



Task

Circle the graph where exactly the right amount of metal has been added

Aim To find out how much iron needs to be added to 2g of copper sulphate

Method You must wear goggles at all times

Task
Exp
Goggles

1 Measure out 25 cm³ of 0.5M copper sulphate solution into a boiling tube
2 Record the initial temperature.
3 Measure out 0.20g** of iron filings.
4 Pour all of the iron into the boiling tube.
5 Swirl and carefully measure the maximum temperature reached.
6 Repeat with 0.40, 0.60, ... 1.40g of iron

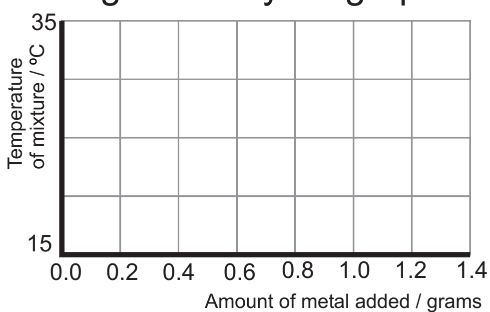
Results

Task

Mass of iron / grams	Maximum temperature reached / ºC
0.0	
0.2	
0.4	
0.6	
0.8	
1.0	
1.2	
1.4	

Graph

Use the following axis for your graph



Conclusion

How much iron is needed to completely react with 2g of copper sulphate ?

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Chemical Masses 3

Aims	
CQ4c H	To calculate molar quantities for provided balanced equations To calculate scaled quantities from molar quantities

Knowing the 'molar quantities' for a reaction makes it easy to calculate and predict the masses for actual experiments.

For example, if **5.0 grams** of **methane** is to be burnt in pure oxygen, predict the mass of **water** (steam) produced. The equation and calculated molar quantities are :

Symbol equation	$\mathbf{CH_4}$	+	$2\ O_2$	=>	CO_2	+	$\mathbf{2\ H_2O}$
Atomic masses	12 + (4 × 1)		2 × (16 + 16)		12 + 16 + 16		2 × (1 + 1 + 16)
Molar quantity	**16 g**		64 g		44 g		**36 g**
	÷ 16		÷ 16		÷ 16		÷ 16
Scale down	**1 g**		4 g		2.75 g		**2.25 g**
	× 5		× 5		× 5		× 5
Scale up	**5 g**		20 g		13.75 g		answer =**11.25 g**

These calculations can be summarized as

(i) Calculate the **molar quantities** using atomic masses
(ii) Scale down all the quantities so that the **highted chemical** equals just **1 gram.**
(iii) Scale up all the quantities to fit the mass of the hightlighed chemical.

Notice that the same scaling up and down steps are used for all chemicals in the question.

Answer the following questions

(1) If **3 grams** of **magnesium** are completely burnt, how much magnesium oxide is made

Equation **2 Mg** + O_2 => 2 MgO

(2) How much potassium nitrate (KNO_3) is needed to prepare **100 g** of **oxygen** for the reaction :

Equation $2\ KNO_3$ => $2\ KNO_2$ + $\mathbf{O_2}$

(3) How much sodium and water are needed to make **50 g** of **hydrogen** according to the equation :

Equation 2 Na + $2\ H_2O$ => 2NaOH + $\mathbf{H_2}$

(4) **95.2 kg** of **ammonia** can be created using how much hydrogen and nitrogen ?
The equation for the production of ammonia :

Equation N_2 + $3\ H_2$ => $\mathbf{2\ NH_3}$

(5) 20 grams of methane and **32 grams** of **oxygen** react to give 22 grams of carbon dioxide and 18 grams of water. Some of the methane is not used up (it is in excess). How much unburnt methane will there be ?

Equation CH_4 + $\mathbf{2\ O_2}$ => CO_2 + $2\ H_2O$

Hint work out how much methane would normally be used first.

Chemical Masses 4

Aims	
CQ4d H	To calculate molar quantities for provided balanced equations To calculate scaled quantities from molar quantities

For the following calcuate the molar quantities and then scale the equations up or down to amount of substance given in the question.

1. How much magnesium must be burned to make 4.0g of magnesium oxide ?

   Equation $2\,Mg + O_2 \Rightarrow 2\,MgO$

2. What mass of calcium oxide (quicklime) is formed when 100g of calcium carbonate (limestone) is heated strongly in a lime kiln ?

   Equation $CaCO_3 \Rightarrow CaO + CO_2$

3. During the production of iron in the Blast Furnace, iron(III) oxide is reduced to iron using carbon monoxide.

   Equation $Fe_2O_3 + 3\,CO \Rightarrow 2\,Fe + 3\,CO_2$

   (a) What mass of carbon monoxide is needed to react completely with 16 tonnes of iron(III) oxide ? (1 tonne = 1 million grams **or** simply cross out word *grams* and write *tonnes*)

   (b) What mass of iron would be produced (from the above amounts) ?

   The carbon monoxide is produced in the furnace by the reaction between carbon (coke) and blasts of warm air (oxygen).

   Equation $2\,C + O_2 \Rightarrow 2\,CO$

   (c) What mass of carbon is required to produce 2.8 tonnes of carbon monoxide ?

4. Copper sulphate is usually blue. This is due to water of crystallisation - when the crystals of copper sulphate are formed, water becomes trapped in the crystals.

   If the blue crystals are heated, the crystals turn into a dry (anhydrous) white powder

   Equation $CuSO_4.5H_2O\,(s) \Rightarrow CuSO_4\,(s) + 5\,H_2O\,(g)$

   What is the mass lost when 1.25g of blue copper sulphate crystals are heated and converted in the anhydrous salt ?

5. The mineral Bauxite can be purified to give white aluminium oxide. This can be used to prepare the metal aluminium, by passing electricity through molten aluminium oxide.

   Equation $2\,Al_2O_3 \Rightarrow 4\,Al + 3\,O_2$

   What is the mass of aluminium which can be obtained from 50 tonnes of aluminium oxide ?

RAMs Mg = 24 : O = 16 : Ca = 40 : C = 12 : Fe = 56 : Cu = 64 : S = 32 : H = 1 : Al =27

Volumes and Masses 1

Aims

CQ5a H

To observe accurate measurement of gas volumes

To calculate molar volume of hydrogen from experimental data

Chemists can easily calculate the **mass** (in grams) of the **reactants** or **products** for a chemical reaction. This is particularly useful for solid substances. However for gases it is more useful to measure the **volume** (in cm³).

Experiment

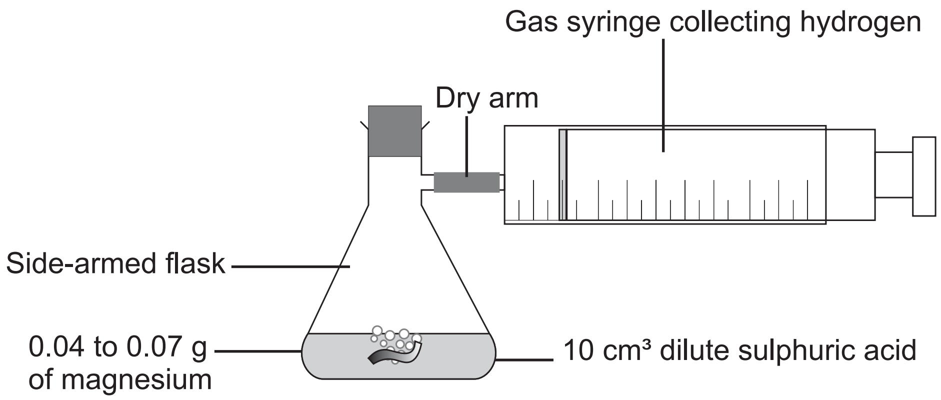
Aim To find the **molar volume** of hydrogen gas produced according to the equation

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

Demo

Exp

In this experiment the hydrogen gas produced is collected and measured in a gas syringe.



The results are then used to predict the volume of gas which would be produced on a molar scale (ie if 24g of magnesium had been used).

Method

1. Measure out 10 cm³ of dilute sulphuric acid in a small measuring cylinder.
2. Carefully pour the acid into a side-armed flask - do not let any liquid enter the dry arm
3. Attach a gas syringe to the flask and clamp the syringe securely.
   Ensure that the clamp does not prevent the plunger of the syringe from moving freely.
4. Weigh out a small length of magnesium ribbon (about 5cm in length) on a balance.
5. Add the magnesium to the flask and quickly cork the apparatus.
6. Gently swirl the flask. When all the magnesium has reacted record the final volume of gas.

Calculation

Task

$$\mathbf{Mg}\ (s) + H_2SO_4\ (aq) \Rightarrow MgSO_4\ (aq) + \mathbf{H_2}\ (g)$$

Mass of magnesium used = **g**
in the experiment

Volume of hydrogen collected = **cm³**
in the experiment

Scaled up

Scaled up

Molar quantity = **24 g**

Molar quantity = **cm³**

The volume predicted from this experiment is often larger than the accepted value **24000 cm³** (or 24 litres). The reaction between the magnesium and acid is **exothermic**.

Task

What does this mean and how could this alter the volume of the hydrogen collected?

Volumes and Masses 2

Aims	
CQ5b H	To calculate gas volumes for provided balanced equations To calculate scaled quantities from molar quantities

Reacting molar quantities of hydrogen and oxygen creates a spectacular explosion. To use a molar quantity, requires measuring out 2g of H_2.

Hydrogen is lighter than air. You cannot fill and easily weigh a balloon of H_2 - the balloon floats upwards!

However 'one molar quantity' of **any** gas room temperature and pressure (20°C and 1 atmosphere) takes up **24000 cm³** (24 litres or 24 dm³). <u>This is an important fact for chemical calculations.</u>

Example calculation

When solid silicon is tipped into fluorine gas, the product, silicon tetrafluoride, is a gas.

Balanced equation	Si (s)	+	2 F_2 (g)	=>	SiF_4 (g)
Molar masses	28 g		76 g		104 g
Molar volumes @ rtp	solid		**2** × 24000 cm³ =48000 cm³		**1** x 24000 cm³ =24000 cm³

Some important things to note

(i) Volumes of **gases** are calculated from the *numbers of molecules* in the balanced equation
(ii) The total mass of products **must** equal the total mass of reactants.
(iii) The total volume of products does **not** have to equal the volume of reactants.
(iv) The condition "@ rtp" should also be quoted (your answers would be larger at higher ºC).
(v) Volumes like masses can be scaled up or down

Answer the following questions on lined paper

1) Work out molar quantities, both masses and volumes, for the following equations

(i) 2 H_2 (g) + O_2 (g) => 2 H_2O (l)
(ii) N_2 (g) + 3 H_2 (g) => 2 NH_3 (g)
(iii) Fe_2O_3 (s) + 3 CO (g) => 2 Fe (s) + 3 CO_2 (g)

2) If 4.8 grams of magnesium are completely burnt, what volume of oxygen is needed for this reaction at room temperature and pressure ?

Equation : 2 Mg + O_2 => 2 MgO

3) What volume of hydrogen would be produced if 92 grams of sodium is added to an excess of water ?

Equation : 2 Na + 2 H_2O => 2 NaOH + H_2

4) How many cm³'s of hydrogen and oxygen are needed to form 36 grams of water ?

Equation : 2 H_2 + O_2 => 2 H_2O

5) 8 grams of methane gas and 32 grams of oxygen reacted to give 22 grams of carbon dioxide and 18 grams of liquid water. Calculate the total starting volume of gases and the final volume of gases.

Equation : CH_4 + 2 O_2 => CO_2 + 2 H_2O

Volumes and Masses 3

Aims	
CQ5c H	To calculate gas volumes for provided balanced equations To calculate scaled quantities from molar quantities

Molar quantities can also be applied to **electrolysis** reactions. This is however a little complex!

During electrolysis changes take place at the **cathode** and at the **anode. Half equations** are used to describe changes taking place.

Molten lithium chloride can be electrolysed to make lithium and chloride gas. During electrolysis the half equations are

at the cathode : $Li^+ + e^- \Rightarrow Li$ = 7g using molar quantities

at the anode : **2** $Cl^- - 2e^- \Rightarrow Cl_2$ = 71g or 24000cm^3

The amount of electrons added or removed must be balanced

this equation has been doubled — at the cathode : **2** Li^+ + **2**e^- => **2** Li = 14g

at the anode : **2** $Cl^- - 2e^- \Rightarrow Cl_2$ = 71g or 24000cm^3

By using the same quantity of electricity at each electrode we can state that for each 14g of lithium made, there will be 71g (24000cm^3) of chlorine. This can be scaled up or down as normal.

Answer the following questions on lined paper

1) Sodium chloride contains the ions Na+ and Cl-. During electrolysis, chlorine is formed at the anode .If 46g of sodium is formed what **volume** of chlorine will be produced ?

At the cathode : $Na^+ + e^- \Rightarrow Na$
At the anode : $2Cl - 2e^- \Rightarrow Cl_2$

2) Lead oxide contains the ions Pb^{2+} and O^{2-}. What **mass** of lead metal is produced if at the same time 8g of oxygen forms at the anode ?

At the cathode : $Pb^{++} + 2e^- \Rightarrow Pb$
At the anode : $2O^{2-} - 4e^- \Rightarrow O_2$

3) Lead bromide contains the ions Pb^{2+} and Br^{1-}. What **mass** of lead metal is produced if at the same time 8g of bromine forms at the anode ?

At the anode : $2Br^{1-} - 2e^- \Rightarrow Br_2$

4) Copper chloride contains the ions Cu^{2+} and Cl^{1-}. What **mass** of copper metal is produced if at the same time 12000cm^3 of chloride forms at the anode ?

At the cathode : $Cu^{++} + 2e^- \Rightarrow Cu$
At the anode : $2Cl^{1-} - 2e^- \Rightarrow Cl_2$

5) Aluminium oxide contains the ions Al^{3+} and O^{2-} and is used in the manufacture of aluminium metal - the source of aluminium oxide is a mineral called bauxite (Al_2O_3)

During electrolysis oxygen is formed at the anode

(i) write the half equation for aluminium ions turning into aluminium atoms
(ii) write the half equation for oxide ions turning into oxygen molecules
(iii) if 54 g of aluminium are formed, what **volume** of oxygen will be formed at the same time ?