Bridge to A-Level Chemistry

Atomic Structure, Formulae and Equations

Name _____

Studying Chemistry A level can be challenging but is also incredibly rewarding.

Here's some advice from our current students:

your future self will thank your present self for working hard

Past paper questions are your best friends

'Revise; then reward yourself with chocolate'

Focus on your work and not your grade

Understanding Chemistry allows you to see the world with a little more understanding.

If you want to do chemistry, do all the work on time and immerse yourself in the content from the start, it helps!

it is difficult but you'll succeed if you stick at it and you'll end up loving it

Anyone who is determined and passionate enough could do it!

It's challenging but if you put the work in from now you will enjoy it

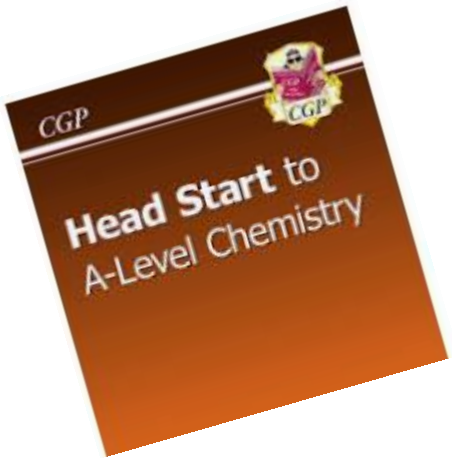
I eventually came to really like it even though it's difficult; everything will make sense in the end just don't give up!

Don't compare your results to other students, everyone has their own path.

"It's a subject that covers some intriguing concepts, some of which that offer real world application which make it even more interesting."

here are some resources to help you prepare:

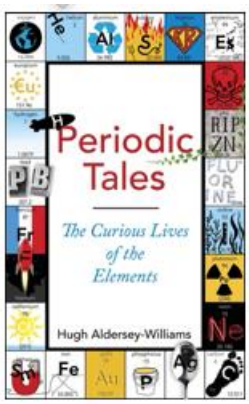
https://filestore.aqa.org.uk/resources/chemistry/AQA-7404-7405-TG.PDF

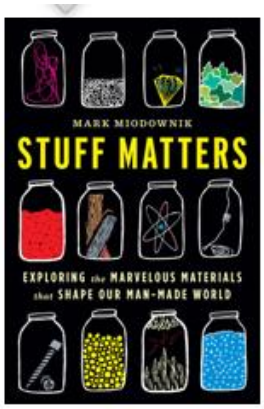


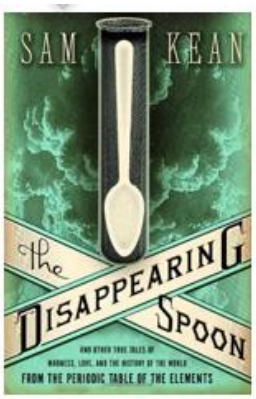
https://www.cgpbooks.co.uk/secondary-books/as-and-a-level/science/chemistry/cbr71-head-start-to-a-level-chemistry

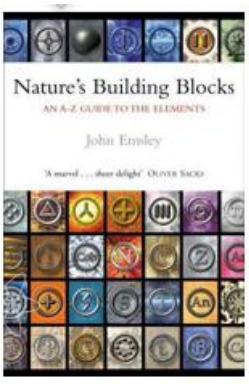
https://www.hoddereducation.co.uk/chemistryreview

Other books for enjoyment and to widen your knowledge of chemistry:









This work book contains topics that cover those aspects of chemistry taught at both GCSE and at A level and to give you a foundation for studying Chemistry at a higher level.

From the specification:

OBJECTIVES:

		Learnt in class	Revised
3.1.1.1	Describe the structure of atoms in terms of PROTONS, NEUTRONS and ELECTRONS		
	Recall the relative mass and relative charge of PROTONS, NEUTRONS and ELECTRONS		
3.1.1.2	Define atoms & ions in terms of numbers of PROTONS, NEUTRONS & ELECTRONS, as well as atomic no & mass no		
	State what is meant by the term ISOTOPE		
	Identify atoms and ions based on the number of PROTONS, ELECTRONS and NEUTRONS		
	Describe the principles of 'Time of flight' mass spectrometry		
	Perform calculations using 'Time of flight' data		
	Use mass spectrometry to identify elements		
	Interpreting mass spectra of molecules		
	Calculate relative atomic mass from mass spectra		
3.1.2.1	Define RELATIVE ATOMIC MASS (Ar)		
	Define RELATIVE MOLECULAR MASS (M_r)		
	Determine relative molecular mass of a substance using Ar values		
3.1.2.4	Explain what is meant by EMPIRICAL FORMULA		
	Explain what is meant by MOLECULAR FORMULA		
	Calculate empirical formula from percentage or composition by mass data		
	Deduce molecular formula from the empirical formula and relative molecular mass		
	Deduce a formula from WATER OF CRYSTALLISATION data		
3.1.3.1	Determine the formula of an ionic compound from its ionic charges		
	Write ionic equations		
	Recall the formulae of some covalent compounds e.g. water, ammonia, methane		
	Deduce the molecular formula of a covalent compound from its name		
	Write balanced equations		
	Write ionic equations		

KEY WORDS FOR THIS TOPIC:

complete the table as you go along

ATOMIC NUMBER	
MASS NUMBER	
DIATOMIC	
ELECTRON	
EMPIRICAL FORMULA	
ISOTOPES	
CRUCIBLE	
MOLECULAR FORMULA	
NEUTRON	
POLYATOMIC	
PROTON	
PROTON NUMBER	
RELATIVE ATOMIC MASS	
RELATIVE FORMULA MASS	
RELATIVE ISOTOPIC MASS	
RELATIVE MOLECULAR MASS	
SPECTATOR IONS	
STATE SYMBOLS	
WATER OF CRYSTALLISATION	
MASS SPECTROMETRY	
ELECTRONSPRAY	
ELECTRON IMPACT	
ABUNDANCE	
M/Z	

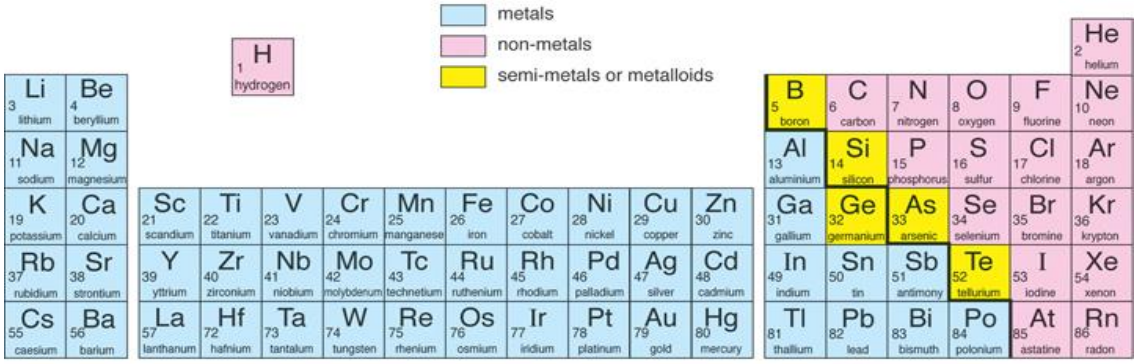
NUMERACY SKILLS:

Addition/multiplication	Relative atomic/molecular mass / A_r calculation
Ratios	Empirical formulae
Decimal places	A_r/M_r
Percentages	Empirical formula, % by mass/ %abundance
Significant figures	All topics
Graphs	Water of crystallisation

WRITING FORMULAE

spec ref: 3.1.3.1

- For some ions the charge can be determined from the group of the periodic table.
- Charges on ions are written as X^{+}, X^{2+} or X^{3+}.
- Some ions have a roman numeral after the name e.g Fe(II) and Cr(III). The *roman numerals* give the *charge* on the ion.



Group 1 metals all have	1+	(removal of 1electron)
Group 2 metals all have	2+	(removal of 2 electrons)
Group 3 metals all have	3+	(removal of 3 electrons)
Group 5 can sometimes be	3-	(addition of 3 electrons)
Group 6 non-metals are often	2-	(addition of 2 electrons)
Group 7 non-metals are often	1-	(addition of 1 electron)

Now complete the following table

Name of ion	Formula (with charge)	Name of ion	Formula (with charge)
Iron (III)		Sulfide	
Aluminium		Chloride	
Iron (II)		Nitride	
Magnesium		Oxide	
Sodium		Fluoride	
Calcium		Iodide	

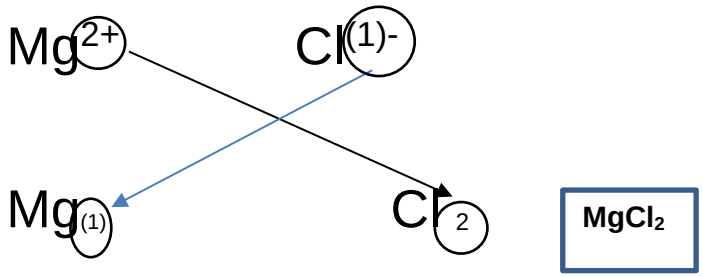
Working out ionic formulae

Chemical formulae (of ionic compounds) are produced by combining ions which may be positively or negatively charged.

Example:	magnesium chloride
Ions present	Mg^{2+} Cl^-
Balance the charges	1 magnesium and 2 chlorides are needed
Formula	$MgCl_2$

Ions present

“Swap the numbers over”



(nb find a common factor if possible and omit (leave out) 1s)

Try to work out the formulae of these…

aluminium iodide……..…calcium sulphide……

sodium oxide …… sodium fluoride……

copper(II) oxide…… aluminium oxide……

barium chloride…… potassium nitride ……

iron(II) bromide…….. copper (I) iodide……

titanium (IV) oxide…… strontium bromide……

Compound ions

These are polyatomic ions – made up of one or more atoms. You need to learn these off by heart

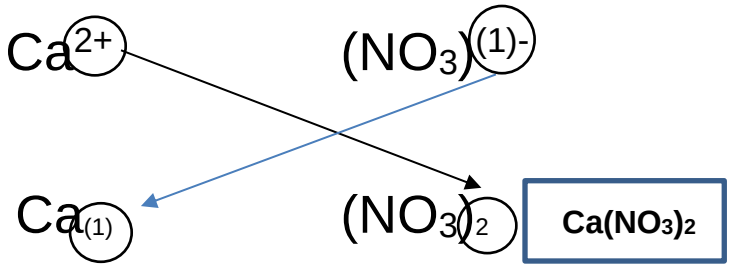
Name of ion	Formula (with charge)	Name of ion	Formula (with charge)
Ammonium		Hydroxide	
		Nitrate (V)	
		Carbonate	
		Sulfate (VI)	

Working out ionic formulae

For compound ions, it is often easier to write brackets around the ion:

Example: calcium nitrate

Ions present



"Swap the numbers over"

iron(II) sulfate…….. potassium nitrate……

aluminium sulfate…….. barium carbonate……

iron(III) carbonate…….. titanium(IV) hydroxide……

ammonium nitrate……..... magnesium hydroxide ……

copper(II) nitrate……..… ammonium carbonate ……

Covalent Formula:

As atoms which bond covalently don't have charges we have to look at their names to give us clues as to the formula:

These prefixes are used:

	Number of atoms
mono…	
di…	
tri…	
tetra….	
penta…	
hexa…	

e.g. carbon ***mon***oxide carbon ***di***oxide

sulphur ***tri***oxide phosphorus ***penta***chloride

Acids are slightly harder to deduce:

Acid	**formula**
Hydrochloric acid	
Sulphuric acid	
Nitric acid	
Phosphoric acid	

Try writing the formula for these compounds:

dihydrogen oxide……. sulphur dioxide……

hydrogen (mono)bromide…… dinitogen tetraoxide……

carbon tetrachloride……. Silicon tetrahydride……

Nb. Organic compounds have their own system of naming (***nomenclature***) which will be covered later in the course

e.g. methane CH_4

ethane C_2H_6 etc

BALANCING EQUATIONS

spec ref: 3.1.2.5

When we balance an equation, we must ensure that the same number of each atom is equal on either side of the equation

Which of these are balanced?

	Y	N
$2H_2 + O_2 \rightarrow 2H_2O$		
$CH_4 + O_2 \rightarrow CO_2 + H_2O$		
$Na + H_2O \rightarrow 2NaOH + H_2$		
$H_2 + Cl_2 \rightarrow 2HCl$		

Now try these: (use a pencil)

…….CH_4(g) +…….. O_2(g) → ……..CO_2(g) + …….H_2O(l)

…….C_3H_8(g) +…….. O_2(g) → ……..CO_2(g) + …….H_2O(l)

…….$C_{10}H_{20}$(g) +…….. O_2(g) → ……..CO (g) + …….H_2O(l)

…….Mg(s) + ……HCl(aq) → ……..$MgCl_2$(aq) +…….. H_2(g)

……Fe_2O_3(s) + ……CO(g) →…….. Fe(s) + ……..CO_2(g)

……CO (g) + ……. NO (g) →……. N_2(g) + ……CO_2(g)

 Key Point { **(s) = Solid, (aq) = Aqueous solution, (l) = Liquid and (g) = Gas** }

BALANCING IONIC EQUATIONS

These do not show the ions that remain unchanged in a reaction. (spectator ions).

This means they are much simpler.

The charges must balance on each side of the equation

 Taught Example

e.g. the balanced equation for the displacement of copper by zinc:

$$Zn\,(s) + CuSO_4(aq) \longrightarrow ZnSO_4(aq) + Cu(s)$$

Step 1: separate anything that is aqueous into the ions:

$$Zn_{(s)} + CuSO_{4(aq)} \longrightarrow ZnSO_{4(aq)} + Cu_{(s)}$$

$$Zn_{(s)} + Cu^{2+}_{(aq)} + SO_4^{2-}{}_{(aq)} \longrightarrow Zn^{2+}_{(aq)} + SO_4^{2-}{}_{(aq)} + Cu_{(s)}$$

Step 2: cancel out naything that appears on either side of the equation

$$Zn_{(s)} + Cu^{2+}_{(aq)} + \cancel{SO_4^{2-}{}_{(aq)}} \longrightarrow Zn^{2+}_{(aq)} + \cancel{SO_4^{2-}{}_{(aq)}} + Cu_{(s)}$$

Step 3: write the ionic equation:

$$Zn_{(s)} + Cu^{2+}_{(aq)} \longrightarrow Zn^{2+}_{(aq)} + Cu_{(s)}$$

Now try these:

1. the reaction between sodium hydroxide (NaOH) and hydrochloric acid (HCl) to give sodium chloride and water

2. the reaction between sodium carbonate (Na_2CO_3) and hydrochloric acid (HCl) to give sodium chloride, carbon dioxide and water

WRITING BALANCED EQUATIONS FROM FORMULAE

Write symbol equations for the following.

a) hydrogen + oxygen → water

b) lithium + water → lithium hydroxide + hydrogen

c) ammonium chloride + calcium hydroxide → ammonia + calcium chloride + water

Occasionally you will be required to write an equation where you don't know all the species involved. You have to deduce the missing reactants (usually oxygen or water) or missing products (usually water or hydrogen in the case of metals and acids)

Write symbol equations for the following reactions:

a) The formation of magnesium oxide from burning magnesium.

……

b) The reaction of sulfur trioxide with water to produce sulfuric acid (H_2SO_4).

……

c) The decomposition of hydrogen peroxide (H_2O_2) to produce oxygen and another non-toxic product.

……

Solid aluminium oxide reacting with concentrated sulfuric acid to form aluminium sulfate and water.

……

Carbon dioxide reacting with calcium hydroxide to form insoluble calcium carbonate and another product

……

Review

Now read over your work from page 6-13 and summarise below.

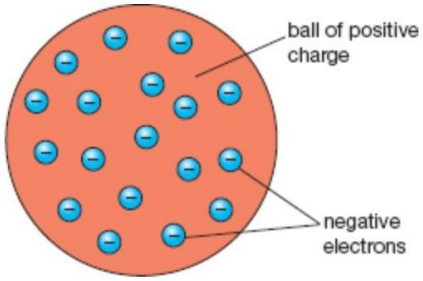
You can write bullet point notes, tabulate information or draw a mind map

FUNDAMENTAL PARTICLES

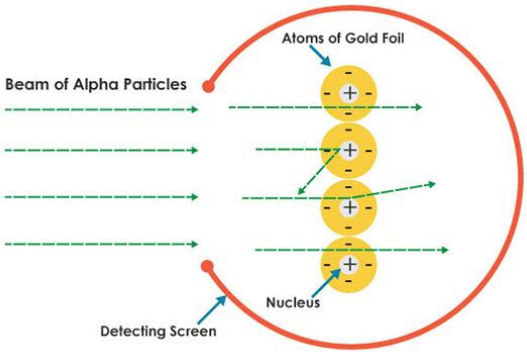
spec ref: 3.1.1.1

Developing the Structure of the Atom

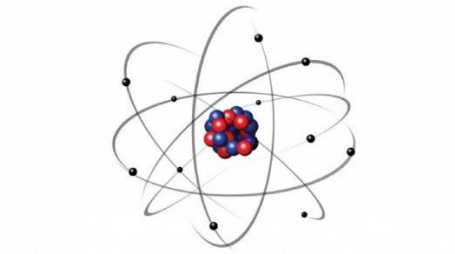
- In 1897, the model of the atom was known as the **'plum pudding model'**



- In 1909, an experiment was carried out, that showed that the plum pudding model was **incorrect**:

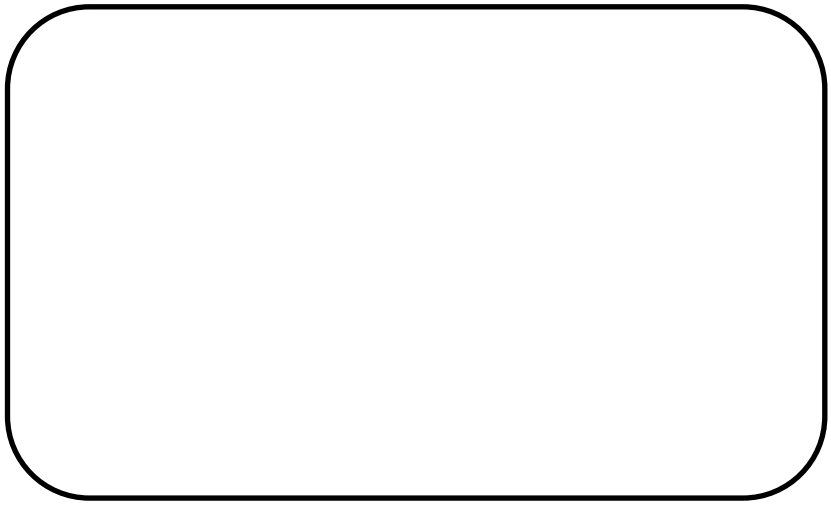


- Positively charged alpha particles (He^{2+} ions) were fired at a very thin sheet of gold.
- If the plum pudding model was correct, **most** alpha particles would be slightly deflected by the positive 'pudding'
- In reality, most of the alpha particles **passed straight through** the gold without any deflection, and **a small amount** were deflected backwards.
- The results indicated that the correct structure of the atom is:
    - A small **positively charged nucleus** *(some He^{2+} deflected backwards)*
    - Surrounded by a **cloud of negative electrons**
    - Most of the atom is **empty space** *(most He^{2+} passed straight through)*



The Bohr model of the atom:

Draw a model of an atom here and label the following particles: PROTON, NEUTRON, ELECTRON, NUCLEUS, and ENERGY LEVEL. (this is the model you know grom GCSE)



ACTIVITY:

research the different theories about the atom through history and create a timeline to indicate the key discoveries that have lead to our current understanding.

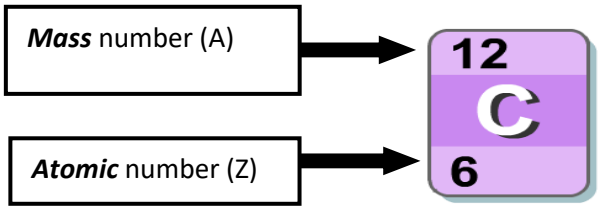
You may find it useful to have a look at the Large Hadron Collider at CERN: https://home.cern/

Complete the table with the relative masses and relative charges of each of the fundamental particles:

	Relative mass	Relative charge
Proton		
Neutron		
Electron		

PROTONS, NEUTRONS AND ELECTRONS

We can use the mass number and atomic number to find out the number of protons, neutrons and electrons in an atom.

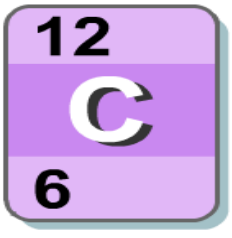


Atomic Number — ***no of protons in an atom***

Mass Number — ***no of protons and neutrons in an atom***

An atom has no overall charge so the number of ***protons*** is ***equal*** to the number of ***electrons***

In this example,



☐ protons

☐ neutrons

☐ electrons

How do you calculate the number of neutrons?

Calculate how many neutrons, protons and electrons are in the following atoms:

Element	symbol	Mass No.	Atomic No.	No. of protons	No. of neutrons	No. of electrons
Hydrogen		1	1			
Carbon				6	6	
Neon		20		10		10
Aluminium			13		14	
Potassium		39	19			

Ions have different numbers of protons and electrons.

A positive ion (cation) has _____ electrons

A negative ion (anion) has _____ electrons

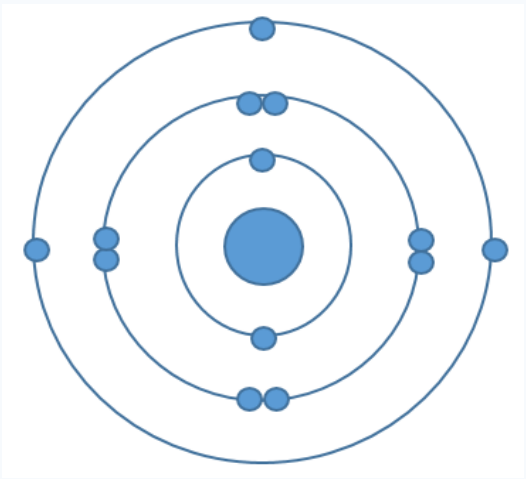
Calculate how many neutrons, protons and electrons are in the following ***ions***:

symbol	Mass No.	Atomic No.	No. of protons	No. of neutrons	No. of electron
$^{1}H^{+}$	1	1			
$^{16}O^{2-}$			8	8	
$^{23}Na^{+}$	23		11		
$^{40}Ca^{2+}$		20		20	
$^{19}F^{-}$	19	9			

A note about electrons:

The arrangement of the electrons determine the reactivity of the atom.

At GCSE we represented the arrangement of electrons as shown below.



Written as.....

This is very simplistic and never used at A Level Chemistry.

You will learn more about this in the Atomic Structure topic.

The electronic configuration of lithium is 2.1
The electronic configuration of potassium is 2.8.8.1
Lithium is less reactive than potassium.

Explain, in terms of their electronic configurations, why lithium is less reactive than potassium.

(3)

MASS NUMBER AND ISOTOPES

spec ref: 3.1.1.2

Isotopes ***atoms which have the same no of protons***

But different no of neutrons

in other words….

They have the same ……***atomic number***……..…

but different ……***mass number***……

Some common isotopes:

element	Common isotopes
chlorine	
Carbon	
Uranium	
hydrogen	

Do isotopes of the same element have the same or different chemical properties? Why?

Which physical properties of isotopes of the same element might be different?

The table shows the mass number and number of neutrons in the nucleus of four atoms: W, X, Y & Z.

a) Complete the table below

	W	X	Y	Z
Mass Number	36	39	40	40
Number of neutrons	18	20	21	22
Atomic Number				
Symbol				

b) Which of the atoms from the table above are isotopes of the same element

…….

Beams of electrons, protons and neutrons are passed separately into a vacuum between row metal plates of positive and negative charge.

Which of the three types of sub-atomic particles are deflected the most?

Give a reason for your answer and state in which direction this type of particle is deflected.

Which of the three types of particle has the greatest penetrating power through a sheet of metal? Give a reason for your answer.

RELATIVE ATOMIC MASS AND RELATIVE MOLECULAR MASS

spec ref: 3.1.2.1

Relative Atomic Mass Ar

The average mass of an atom compared to

1/12 of the mass of one atom of carbon-12

These are the values given on the periodic table

Use your periodic table to complete the table:

atom	Relative atomic mass (Ar)	atom	Relative atomic mass (Ar)
B		**Cl**	
N		**Cu**	
Na		**Au**	

Relative molecular mass Mr *(Also known as Relative Formula Mass**)***

The average mass of a molecule compared to

1/12 of the mass of one atom of carbon-12

Taught Example

- What is the relative formula mass of sodium hydroxide (NaOH)?

	Ar	***multiples?***		
Na….	23	x 1	23.0	
O…..	16	x 1	+16.0	
H……	1	x 1	+1.0 =	**40.0**

- What is the relative formula mass of magnesium hydroxide ($Mg(OH)_2$)?
  Ar ***multiples?***

Mg….

O…..

H……

Use a Periodic Table to calculate the ***relative formula mass*** of the following substances.

O_2_____ CuO _____

$CaCO_3$ _____ Cl_2_____

NH_4NO_3_____ $Al_2(SO_4)_3$_____

$Zn(OH)_2$_____ $CuSO_4.5H_2O$_____

C_3H_7OH_____

This is the water of crystallisation – you must multiply the Mr of water (18) x 5 and include it in your sum

Identify X in the following compounds

$C_6H_3(NO_2)_x = 213\ gmol^{-1}$

$C_2H_4Cl_x = 99\ gmol^{-1}$

$C_2H_4(COOH)_x = 118\ gmol^{-1}$

$XCl_4^{2-} = 200.9\ gmol^{-1}$

$[Al(OH)_x]^{3-} = 129\ gmol^{-1}$

$X_2CO_3 = 106\ gmol^{-1}$

Review

Now read over your work from page 15-24 and summarise below.

You can write bullet point notes, tabulate information or draw a mind map

EMPIRICAL AND MOLECULAR FORMULA

spec ref: 3.1.2.4

Chemical formulae tell us how many of each kind of atom make up a substance.

Some substances are ***diatomic:*** e.g. H_2 N_2 O_2 F_2 Cl_2 Br_2 I_2

Some substances are ***polyatomic:*** e.g. H_2O NaOH

In the case of **glucose**:

1 molecule contains **6** atoms of **carbon**
12 atoms of **hydrogen**
6 atoms of **oxygen**

The formula is

Molecular Formula ***actual number of atoms of each element in a compound***

We can look at this formula more simply and see it as a ratio of different types of atoms:

carbon atoms : hydrogen atoms: oxygen atoms

6 : 12 : 6

This ratio is written as an EMPIRICAL formula:

Empirical Formula ***simplest whole number ratio of atoms of each element in a compound***

Try these:

Compound	Molecular Formula	Empirical Formula
Hydrogen peroxide		
ethane		
Ethanoic acid	**CH_3COOH**	
Ethene		

Often the empirical formula is the same as the molecular formula

e.g carbon dioxide: _____ water: _____

Taught Example

- Calculate the empirical formula of a substance that has the following masses of each element.

  2.4 g carbon 0.4 g hydrogen 3.2 g oxygen.

Make a column for each element	C	H	O
Step 1: write the mass (or percentage) and divide it by its A_r	$\frac{2.4}{12}$	$\frac{0.4}{1}$	$\frac{3.2}{16}$
Step 2: dividing all the answers by the smallest answer	$\frac{0.2}{0.2}$	$\frac{0.4}{0.2}$	$\frac{0.2}{0.2}$
Step 3: Find the simplest whole number ratio	1	2	2
Step 4: Write the empirical formula	CH_2O		

Another example:
Sodium thiosulfate contains 29.1% of sodium, 40.5% of sulphur and 30.4% of oxygen. What is the empirical formula?

Make a column for each element	Na	S	O
Step 1: write the mass (or percentage) and divide it by its A_r	$\frac{29.1}{23}$	$\frac{40.5}{32.1}$	$\frac{30.4}{16}$
Step 2: dividing all the answers by the smallest answer	$\frac{1.27}{1.27}$	$\frac{1.27}{1.27}$	$\frac{1.90}{1.27}$
Step 3: Find the simplest whole number ratio	1	1	1.49
1.49 or 1.5 cannot be rounded up to 2. Instead all ratios must be multiplied till they are whole numbers			
Step 4: Write the empirical formula	1 : 1 : 1.5 X2 becomes 2 : 2 : 3 $Na_2S_2O_3$		

 Now try these:

1. Compound X contains 27.3% carbon and 72.7% oxygen by mass. Calculate the empirical formula of X

2. Compound Z is known to contain iron and chlorine. 2.5 g of Z is found to contain 0.855g iron. Calculate the empirical formula of Z

3. Compound A is an oxide containing 53% aluminium by mass. Calculate the empirical formula of A.

4. A dodgy liquid from an old refrigerator found on a scrap heap was found to contain a compound with the following composition: 11.4% carbon, 34.0% chlorine and the remainder being fluorine. Calculate its empirical formula.

Extension questions:

5. Compound Q is a hydrocarbon containing 81.8% carbon by mass. Calculate the empirical formula of Q.

6. 5g of a compound was found to have 1.955g carbon, 0.435g of hydrogen and the rest oxygen. Calculate its empirical formula.

7. A compound was found to have 52.1% carbon, 13.0% hydrogen and 34.8% oxygen. Calculate its empirical formula.

Answers….

1. CO_2 2. $FeCl_3$ 3. Al_2O_3 4. $CClF_3$ 5. C_3H_8 6. $C_3H_8O_3$ 7. C_2H_6O

Calculating The Molecular Formula From The Empirical Formula

If the empirical formula is known and the relative formula mass is known and the molecular formula can be deduced:
In most cases the empirical formula must first be calculated.

Taught Example

- A hydrocarbon is known to contain 85.7% by mass of Carbon and 14.3% by mass of Hydrogen. relative formula mass **(M_r) = 56**. Calculated the empirical formula and find the molecular formula of a compound.

Step 1:	Carbon	Hydrogen
	85.37 ÷ 12 = 7.11	14.3 ÷ 1 = 14.3
	7.11 ÷ 7.11 = 1	14.3 ÷ 7.11 = 2

Empirical formula = CH_2

Step 2: Work out the mass of the empirical formula ("empirical mass")

CH_2 12 + 2 = 14

Step 3: divide the Mr by the empirical mass

56 ÷ 14 = 4 (this is the multiple)

Step 4: multiply the empirical formula by the 'multiple'

CH_2 x 4 = C_4H_8

Molecular formula = CH_2

Now try these:

1. Compound A contains 12.78% carbon, 2.13% hydrogen and 85.20% bromine by mass. Calculate the empirical formula of A. Given the relative formula mass of A is 188, determine its molecular formula

2. A hydrocarbon contains 85.70% by mass of carbon.
Calculate its empirical formula. Given the relative molecular mass is 84, calculate its molecular formula

3. Analysis of a chloride of sulphur, Z, was found to have 47.4% sulphur by mass. Z has a relative formula mass of 135. Calculate the empirical and molecular formula.

Extension question:

4. Analysis of a 1.80g of hydrocarbon X shows that it contains 1.44g of carbon.

a)Calculate the empirical formula of hydrocarbon X. Given the relative formula mass of the hydrocarbon is 30, calculate its molecular formula

A compound has the composition by mass:

H, 5.00%; N, 35.00%; O, 60.00%.

Which compound has this composition?

A HNO_3

B NH_4NO_3

C HNO_2

D NH_2OH

Your answer

Answers….

1.a CH_2Br $C_2H_4Br_2$ 2. CH_2 C_6H_{12} 3 SCl S_2Cl_2 4.Mass of H: 0.36g CH_3 C_2H_6

5 B