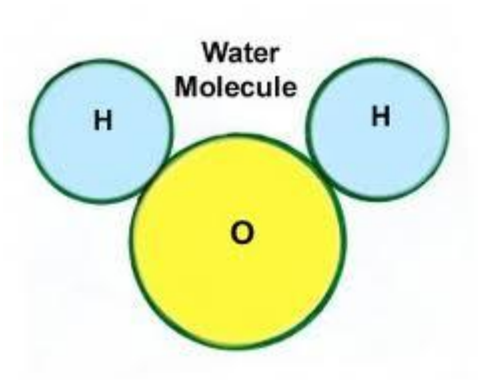
Topic 4 National Chemistry Summary Notes

Formulae, Equations, Balancing Equations and The Mole

LI 1

The chemical formula of a *covalent molecular* compound tells us the number of atoms of each element present in the compound.
E.g. Water H_2O -The formula tells us that there are 2 Hydrogen atoms and 1 oxygen atom present in each water molecule.



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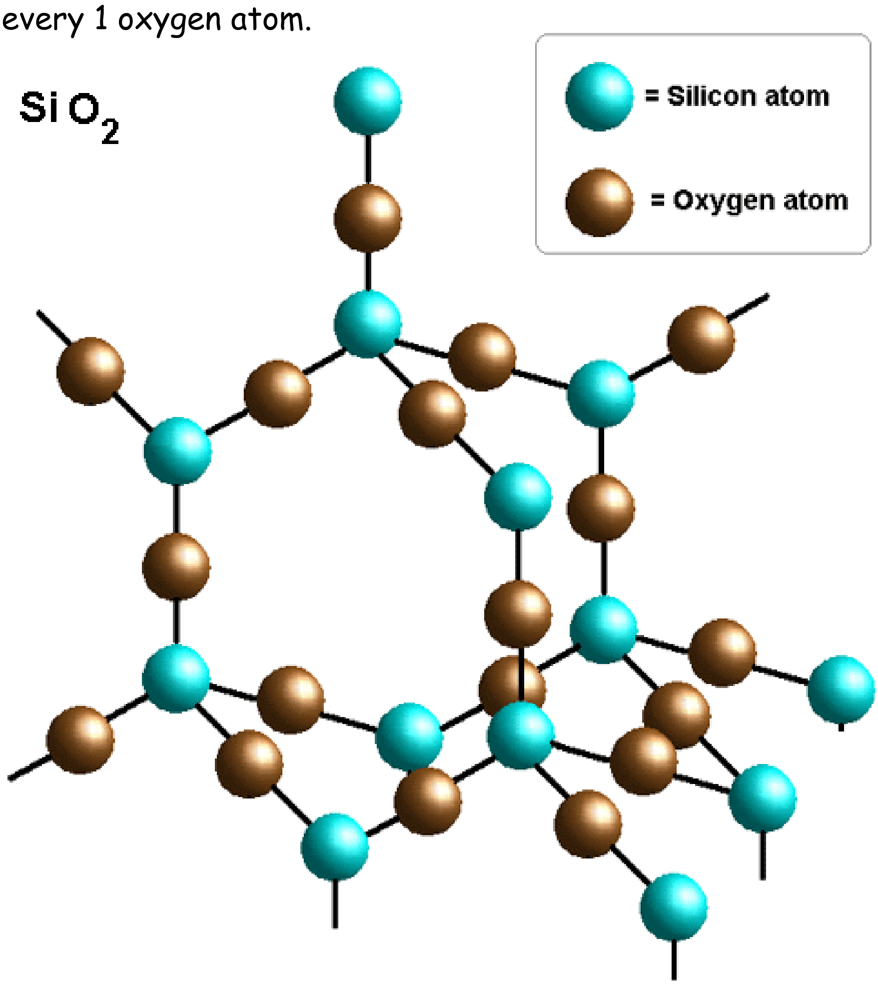
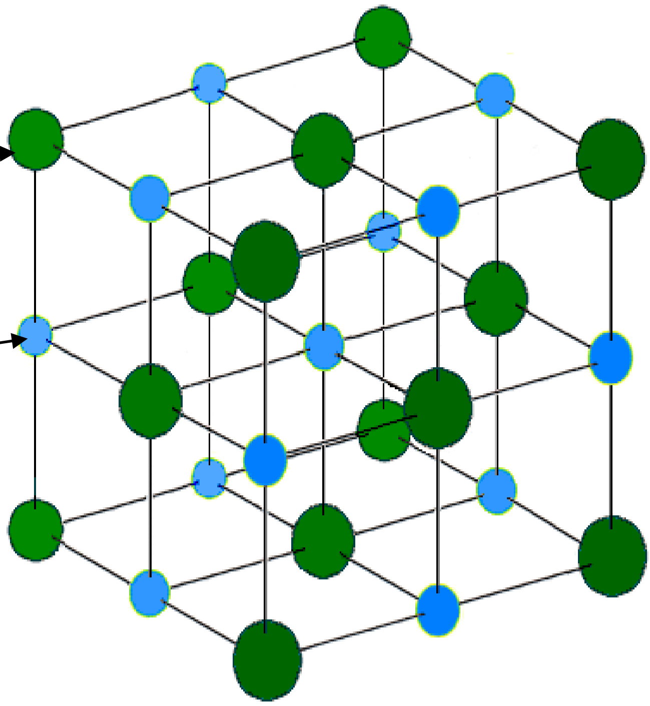
The chemical formula of a *covalent network* tells us the ratio of the elements present.
E.g. Silicon dioxide, SiO_2 structure-The formula tells us there are 2 silicon atoms present for every 1 oxygen atom.



The chemical formula of an *ionic* compound tells us the ratio of the elements present.

E.g. Sodium chloride, NaCl – The formula tells us there is one ion of sodium for every one ion of chlorine



Sodium chloride, NaCl, structure

LI 2

1. CHEMICAL FORMULA FOR ELEMENTS

The chemical formula of an element is simply its' symbol

e.g.

Magnesium	**Mg**
Iron	**Fe**
Phosphorus	**P**
Argon	**Ar**

However some elements exist as two atoms joined together. These are known as the **DIATOMIC ELEMENTS.** There are 7 diatomic elements.

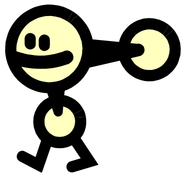
Whenever we write the chemical formula of these elements we put a subscript '2' beside them

e.g.

Iodine	I_2	**I** n
Oxygen	O_2	**O** ctober
Chlorine	Cl_2	**C** hildren
Bromine	Br_2	**B** uy
Nitrogen	N_2	**N** asty
Hydrogen	H_2	**H** alloween
Fluorine	F_2	**F** oods

We can use the mnemonic to help us remember the diatomic elements

LI 3



2. USING VALENCY

The valency of an atom or ion is the number of electrons it shares, loses or gains in a chemical reaction to become stable i.e. the number of bonds it forms with other atoms

Group number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**0**
Valency	**1**	**2**	**3**	**4**	**3**	**2**	**1**	**0**

We can use valency to work out chemical formulae for simple compounds containing two elements i.e. compounds ending in **–IDE**

Remember HYDROXIDES and CYANIDES are exceptions to -IDE rule

We can follow a set of simple rules to write chemical formula:

1. Write symbols of elements present in compound
2. Put valency above each symbol
3. Cross valency over (swap and drop)
4. Cancel down ratio if necessary
5. Write correct chemical formula

Example 1. Sodium chloride

1. Na Cl
2. Na^1 Cl^1
3. Na_1 Cl_1
4. (Not needed)
5. **NaCl**

Example 2. Calcium bromide

1. Ca Br
2. Ca^{2} Br^{1}
3. Ca_{1} Br_{2}
4. (Not needed)
5. **<u>$CaBr_{2}$</u>**

Example 3. Magnesium oxide

1. Mg O
2. Mg^{2} O^{2}
3. Mg_{2} O_{2}
4. Mg_{1} O_{1}
5. **<u>MgO</u>**

Example 4. Germanium oxide

1. Ge O
2. Ge^{4} O^{2}
3. Ge_{2} O_{4}
4. Ge_{1} O_{2}
5. **<u>GeO_{2}</u>**

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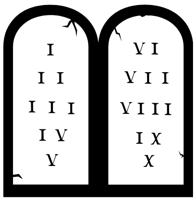
3. ROMAN NUMERALS



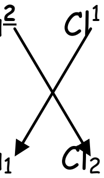
Some elements, particularly the transition metals in the centre block of the periodic table can have more than one valency. Roman numerals are often used to show the valency for these elements.

Roman Numeral	Valency
I	1
II	2
III	3
IV	4
V	5
VI	6

We then follow the same set of valency rules as before.

Example 1. Copper(II) chloride

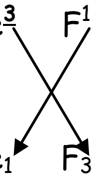
1. Cu Cl
2. Cu^2 Cl^1



3. Cu_1 Cl_2
4. (Not needed)
5. **$CuCl_2$**

Example 2. Iron(III)fluoride

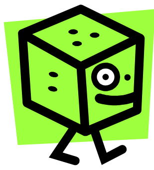
1. Fe F
2. Fe^3 F^1



3. Fe_1 F_3
4. (Not needed)
5. **FeF_3**

Example 3. Manganese(IV)oxide

1. Mn O
2. Mn^4 O^2
3. Mn_2 O_4
4. Mn_1 O_2
5. **MnO_2**



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4. PREFIXES

In the names of some compounds the ratio of atoms present can be indicated by prefixes.

If no prefix is given then it is assumed that only **one** atom of that element is present

Prefix	Meaning
Mono	1
Di	2
Tri	3
Tetra	4
Penta	5
Hexa	6

AS SOON AS YOU SEE A PREFIX ANYWHERE IN THE NAME OF A COMPOUND **DO NOT** USE CROSS VALENCY METHOD AND NEVER CANCEL DOWN RATIOS !

Examples

Carbon **mono**xide	CO
Nitrogen **di**oxide	NO_2
Phosphorus **tri**chloride	PCl_3
Phosphorus **penta**chloride	PCl_5
Dinitrogen **tetr**oxide	N_2O_4

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5. COMPOUNDS CONTAINING COMPLEX IONS

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Complex ions contain more than one kind of atom.

The table below contains some common complex ions

one positive		one negative		two negative		three negative	
Ion	**Formula**	**Ion**	**Formula**	**Ion**	**Formula**	**Ion**	**Formula**
ammonium	NH_4^+	ethanoate	$CH_3COO^–$	carbonate	$CO_3^{2–}$	phosphate	$PO_4^{3–}$
		hydrogencarbonate	$HCO_3^–$	chromate	$CrO_4^{2–}$		
		hydrogensulphate	$HSO_4^–$	dichromate	$Cr_2O_7^{2–}$		
		hydrogensulphite	$HSO_3^–$	sulphate	$SO_4^{2–}$		
		hydroxide	$OH^–$	sulphite	$SO_3^{2–}$		
		nitrate	$NO_3^–$				
		permanganate	$MnO_4^–$				

The valency of a complex ion is the same as the value of the charge of the ion

e.g. NH_4^+ **1** positive charge so valency = **1**
CO_3^{2-} **2** negative charge so valency = **2**

When writing chemical formulae with complex ions always put these ions **INSIDE A BRACKET**.

e.g. NH_4^+ becomes **(NH_4)**
CO_3^{2-} becomes **(CO_3)**
PO_4^{3-} becomes **(PO_4)**

We can use the same cross valency method for writing chemical formulae for compounds containing complex ions

Example 1 Potassium phosphate

1. K (PO_4)
2. K^1 $(PO_4)^3$
3. K_3 $(PO_4)_1$
4. (Not needed)
5. $K_3(PO_4)$

> Note: Brackets are **not** needed if there is only **one** complex ion in the formula so $K_3(PO_4)$ could be written as K_3PO_4

Example 2 Magnesium sulphate

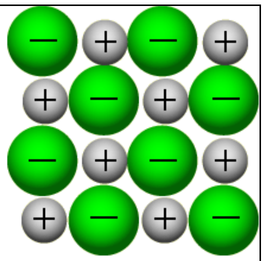
1. Mg (SO_4)
2. Mg^2 $(SO_4)^2$
3. Mg_2 $(SO_4)_2$
4. $Mg(SO_4)$
5. $Mg(SO_4)$ or $MgSO_4$

Example 3 Calcium nitrate

1. Ca (NO_3)
2. Ca^2 $(NO_3)^1$
3. Ca_1 $(NO_3)_2$
4. $Ca(NO_3)_2$
5. $Ca(NO_3)_2$

Example 4 Ammonium hydroxide

1. (NH_4) (OH)
2. $(NH_4)^1$ $(OH)^1$
3. $(NH_4)_1$ $(OH)_1$
4. (NH_4) (OH)
5. (NH_4) (OH) or NH_4OH



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6. IONIC FORMULA

The ionic formula shows the charges of the ions present in an ionic substance.

The value of the charge on an ion is the same as the valency.

METALS form POSITIVE IONS

NON-METALS form NEGATIVE IONS

GROUP NUMBER	1	2	3	4	5	6	7	0	
VALENCY	1	2	3	4	3	2	1	0	
CHARGE ON ION	**1+**	**2+**	**3+**	**4**	**3-**	**2-**	**1-**	**0**	

* Group 4 elements do not usually form ions on their own

Example 1 Lithium chloride

Use the previous valency rules as normal

1. Li   Cl
2. Li^{1} Cl^{1}
3. Li_{1} Cl_{1}
4. (Not needed)
5. Li Cl

To obtain the ionic formula another step is needed.

Step6. Add the charges to ions using the table above or the data book in case of a complex ion. If there is more than 1 of the ion, put the ion and charge in a bracket.

Lithium is a group 1 metal so has a 1^{+} charge. Chlorine is a group 7 non metal so has a 1^{-} charge.

6. **$Li^{+}Cl^{-}$**

Example 2 Calcium oxide

1. Ca O
2. Ca^{2} O^{2}
3. Ca_{2} O_{2}
4. Ca_{1} O_{1}
5. Ca O
6. $\mathbf{Ca^{2+}O^{2-}}$

Example 3 Barium chloride

1. Ba Cl
2. Ba^{2} Cl^{1}
3. Ba_{1} Cl_{2}
4. (Not needed)
5. $BaCl_2$
6. $\mathbf{Ba^{2+}(Cl^{-})_2}$

Example 4 Iron(III) sulphide

1. Fe S
2. Fe^{3} S^{2}
3. Fe_{2} S_{3}
4. (Not needed)
5. Fe_2S_3
6. $\mathbf{(Fe^{3+})_2(S^{2-})_3}$

Example 5 Ammonium phosphate

1. (NH_4) (PO_4)
2. $(NH_4)^{1}$ $(PO_4)^{3}$
3. $(NH_4)_{3}$ $(PO_4)_{1}$
4. (Not needed)
5. $(NH_4)_3$ (PO_4)
6. $(NH_4^{+})_3$ (PO_4^{3-})

LI 8

Equations

Word equations

A shorthand way of showing what goes on in a chemical reaction is to write a **WORD EQUATION**.
Substances you start with are called **REACTANTS.** These appear on the left hand side of the equation.
Substances that form are called **PRODUCTS**. These appear on the right hand side of the equation.
In a word equation '+' means 'and' and the → means 'produces'.

e.g. magnesium burns in oxygen to produce magnesium oxide.

magnesium + oxygen → magnesium oxide

REACTANTS ↑ PRODUCT(S) ↑

Chemical equations

A chemical equation is when the words in an equation are replaced by the chemical formula.

e.g. **magnesium + oxygen → magnesium oxide**

So the chemical equation is $Mg + O_2 \rightarrow MgO$

Formula for magnesium is Mg as it is an element
Formula for oxygen is O_2 as it is a diatomic element
Formula for magnesium oxide is MgO (use valency rules)

Example 1 Rewrite the following word equation as a chemical formula

hydrogen + oxygen → hydrogen oxide

Answer

$$H_2 + O_2 \rightarrow H_2O$$

LI 9 Balancing equations

When we write chemical equations many of them will not have the same number of each atom at the start of the reaction as we have at the end. We call this an unbalanced equation.

e.g. Unbalanced Equation :- $CH_4 + O_2 \rightarrow H_2O + CO_2$

If we count how many atoms of each type are on each side of the equation you will see they are not the same.

Reactants side	Products side
1 C	1C
4H	2H
2O	3O

In order to balance an equation we have to follow these steps.

Step 1: Start by finding out how many atoms of each type are on each side of the equation. (Some teachers recommend making a little table listing the numbers of each atom for the left hand side and for the right hand side.)

Step 2: Next, look for an element which is in only one chemical on the left and in only one on the right of the equation. (But it is usually a good idea to leave hydrogen and oxygen until you've done the others first.)

Step 3: Balance that element by multiplying the chemical species on the side which doesn't have enough atoms of that type by the number required to bring it up to the same as the other side. (It doesn't have to be a whole number). The number must go in FRONT of the formula.

Step 4: Now look for the next element or species that is not balanced and do the same thing.
Repeat until you are forced to balance the hydrogen and oxygen atoms.

Note: If there is a complex ion, on each side of the equation that has remained intact, then that can often be balanced first, as it is acts as a single species. The ions NO_3^- and CO_3^{2-} are examples of a complex ion.

Example 1: How to balance the equation,

$$CH_4 + O_2 \rightarrow H_2O + CO_2$$

1.

Reactants side	Products side
1 C	1C
4H	2H
2O	3O

Equation is NOT balanced

2. Balance the H atoms by putting 2 in FRONT of the H_2O so we have 4 H atoms on each side. Note: This will also increase the number of O atoms.

$$CH_4 + O_2 \rightarrow 2H_2O + CO_2$$

Reactants side	Products side
1 C	1C
4H	4H
2O	4O

3. Balance the O atoms by putting 2 in FRONT of the O_2 so we have 4 O atoms on each side.

$$CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$$

Reactants side	Products side
1 C	1C
4H	4H
4O	4O

The equation is now balanced

Example 2: How to balance the equation,

$$CaCO_3 + HCl \rightarrow CaCl_2 + H_2O + CO_2$$

1.

Reactants side	Products side
1 Ca	1 Ca
1 C	1 C
3 O	3 O
1 H	2 H
1 Cl	2 Cl

Equation is NOT balanced

2. Balance the Cl atoms by putting 2 in FRONT of the HCl so we have 2 Cl atoms on each side.

$$CaCO_3 + \mathbf{2}HCl \rightarrow CaCl_2 + H_2O + CO_2$$

Reactants side	Products side
1 Ca	1 Ca
1 C	1 C
3 O	3 O
2H	2 H
2 Cl	2 Cl

The equation is now balanced

Example 3 How to balance the equation,

$$Al + FeO \rightarrow Al_2O_3 + Fe$$

1.

Reactants side	Products side
1 Al	2Al
1 Fe	1 Fe
1 O	3 O

2. Balance the Al atoms by putting 2 in FRONT of the Al so we have 2 Al atoms on each side.

$$\mathbf{2}Al + FeO \rightarrow Al_2O_3 + Fe$$

Reactants side	Products side
2 Al	2Al
1 Fe	1 Fe
1 O	3O

3. Balance the O atoms by putting 3 in FRONT of the FeO so we have 3 O atoms on each side.

$$2Al + \mathbf{3}FeO \rightarrow Al_2O_3 + Fe$$

Reactants side	Products side
2 Al	2Al
3Fe	1 Fe
3 O	3O

4. Balance the Fe atoms by putting 3 in FRONT of the Fe so we have 3 Fe atoms on each side.

$$2Al + 3FeO \rightarrow Al_2O_3 + \mathbf{3}Fe$$

Reactants side	Products side
2 Al	2Al
3Fe	3 Fe
3 O	3O

The equation is now balanced

LI 10 **<u>Formula mass in grams</u>**

The formula mass of a substance is worked out by adding the relative atomic masses of all the elements present in the formula.

1. Write the formula for the compound.
2. Determine how many of each atom are in the compound. If there is a number outside any brackets, multiply the number of atoms in the bracket by this number. If there is no number, assume it is one.
3. Multiply the number of atoms by its atomic weight. (Every teacher is different but my students must round the atomic weight to the tenth's place.
4. Add your results, don't forget to add g for grams

Example 1: Calculate the formula mass of calcium chloride.

1. $CaCl_2$

2. Ca = 1
   Cl = 2

3. 1 Ca = 1 x 40 = 40
   2 Cl = 2 x 35·5 = 71

4. 40 + 71 = **<u>111g</u>**

Example 2: Calculate the formula mass of calcium carbonate.

1. $CaCO_3$

2. Ca = 1
   C = 1
   0 = 3

3. 1 Ca = 1 x 40 = 40
   1 C = 1 x 12 = 12
   3 O = 3 x 16 = 48

4. 40 + 12 + 48 = **<u>100g</u>**

Example 3: Calculate the formula mass of ammonium phosphate.

1. $(NH_4)_3PO_4$

2. N = 3
   H = 12
   P = 1
   O = 4

3. 3 N = 3 x 14 = 42
   12 H = 1 x 12 = 12
   1 P = 1 x 31 = 31
   4 O = 4 x 16 = 64

4. 40 + 12 + 31 +64 = **147g**

LI 11

The Mole

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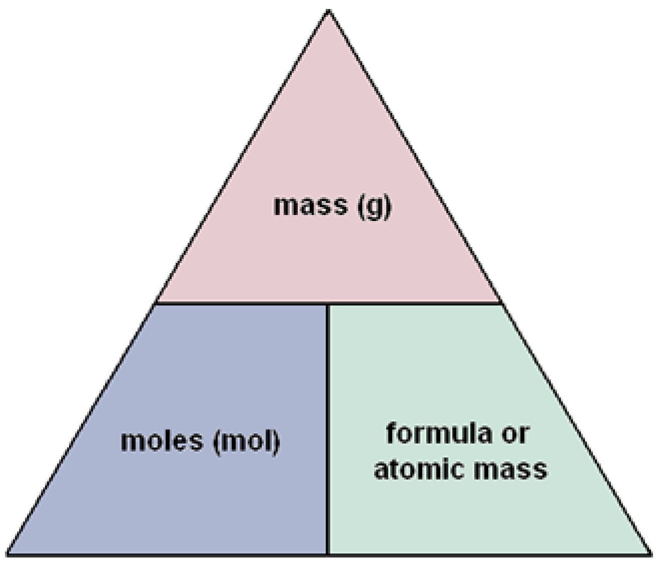
A mole of a substance is the formula mass in grams. e.g. the formula mass in grams for H_2O is 18g so we say that one mole of H_2O is 18g.
For any substance the mass present can be calculated by using the following equation

Mass = number of moles x mass of 1 mole (FM in grams)

Rearranging gives

$$\text{Number of moles} = \frac{\text{mass of substance in grams}}{\text{formula mass}}$$



Example 1: Calculate the mass of 4 moles of carbon dioxide, CO_2.

Mass of CO_2 = number of moles X formula mass
= 4 X [12 + (2x16)]
= 4 X 44
= **176g**

Example 2: How many moles are there in 100g of carbon hydride, CH_4.

Number of moles of CH_4 = $\frac{\text{mass of substance in grams}}{\text{formula mass}}$

= $\frac{100}{[12+(4x1)]}$ = $\frac{100}{16}$

= **6·25 moles**

Example 3: What is the mass of two moles of sodium chloride, NaCl?

Mass of NaCl = number of moles X formula mass
= 2 X (23 + 35·5)
= 2 x 58·5
= **117g**

LI 12

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Using concentration

As we now have a standard amount of any substance we can now work out the **concentration** of a solution.

Concentration is **a measure of how much solute is dissolved** in the solution. The more dissolved the higher the concentration.

As the amount of solid is the Mole, then the concentration is measured as the **number of moles of solute dissolved in 1 litre of solution**. The unit is **Moles per litre (mol/l) sometimes written as mol l^{-1}.**

i.e. A solution labelled as 1 mol/l contains 1 mole of substance dissolved in one litre of water

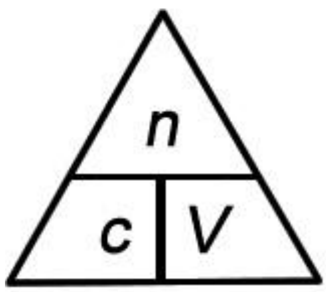
For any solution, the concentration can be calculated by using the following equation

$$\text{Concentration} = \frac{\text{number of moles}}{\text{Volume (in litres)}}$$

Rearranging gives

number of moles= Concentration x Volume (in litres)

These equations can be summarised in the triangle



Example 1: How many moles are there in 100 cm^3 of sodium hydroxide solution, concentration 0.4 mol l^{-1}?

Number of moles = Concentration x Volume (in litres)
= 0.4 x (100÷1000)
= 0.4 x 0.1
= **0.04 moles**

Example 2: What is the concentration of a solution of hydrochloric acid containing 0.1 mol in 50 cm^3?

$$\text{Concentration} = \frac{\text{number of moles}}{\text{Volume (in litres)}}$$

= 0.1 ÷ (50÷1000)
= **2 mol/l**

Example 3: What volume of a sodium carbonate solution, concentration 2 mol/l contains 0.5 mol?

$$\text{Volume (in litres)} = \frac{\text{number of moles}}{\text{Concentration}}$$

= 0.5÷ 2
=**0.25 l** (or 250 ml)

Calculations involving both triangles.

Some calculations will require using both triangles.

Example 4: What is the concentration of a solution containing 2 g sodium hydroxide, NaOH, in 50 cm solution?

$$\text{Concentration} = \frac{\text{number of moles}}{\text{Volume (in litres)}}$$

However we do not yet know the number of moles so we must firstly calculate this using the equation

$$\text{Number of moles} = \frac{\text{mass of substance in grams}}{\text{formula mass}}$$

Formula mass of NaOH = (23+16+1)
= 40g

$$\text{Number of moles} = \frac{\text{mass of substance in grams}}{\text{formula mass}}$$

= 2 ÷ 40
= 0.05 moles

Concentration = $\frac{\text{number of moles}}{\text{Volume (in litres)}}$

= 0.05 ÷ (50÷1000)
= 0.05 ÷ 0.05
= **1 mol/l**

Example 5: How many grams of calcium chloride, $CaCl_2$, are there in 25 cm^3 of a solution, concentration 0.1 mol l^{-1}?

number of moles = Concentration x Volume (in litres)
= 0.1 x (25 ÷ 1000)
= 0.0025 moles

Formula mass of $CaCl_2$ = 40 + (2x 35.5)
= 111g

mass of substance in grams = Number of moles x formula mass
= 0.0025 x 111
= **0.2775g**

LI 13

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Making a standard solution

A **standard solution** is a solution whose concentration is known accurately. When making up a standard solution it is important that the correct mass of substance is accurately measured. It is also important that all of this is successfully transferred to the volumetric flask used to make up the solution. The following procedure will make sure that this happens.

Background calculations

1. Work out the number of moles needed to make up a solution with the required volume and concentration.

2. Now work out the relative formula mass, of the chosen substance.

3. Work out the mass of substance needed using your answers from steps 1 and 2.

Making up the solution

1. Take a watch glass and place it on the balance. Tare the balance (set it to zero). Carefully weigh out the required mass of substance.
2. Transfer this amount to a beaker. Add water from a wash bottle to dissolve it. Use some of the water to rinse all the substance off the watch glass. Do this at least twice.
3. Stir with a glass rod until all the solid is dissolved, then transfer the solution to the volumetric flask. Use more water from the wash bottle to rinse out the beaker and the glass rod. Do this at least twice.
4. Add water to just below the line on the volumetric flask. Add the final drops with a teat pipette to ensure that the bottom of the meniscus is on the line.
5. **Put the stopper on the flask** and turn the flask over a couple of times to mix the solution.

Example: Making up a 0.1 mol/l solution of sodium chloride, NaCl, using a 250ml volumetric flask

1. Number of moles = concentration x volume in litres
= 0.1 x (250 ÷ 1000)
= 0.1 x 0.25
= 0.025 moles

2. Formula mass of NaCl = 23+35.5
= 58.5g

3. mass = number of moles x formula mass
= 0.025 x 58.5
= 1.4625g

Procedure

1. Take a watch glass and place it on the balance and set it to zero. Carefully weigh out 1.4625g of sodium chloride
2. Transfer this to a beaker. Add water from a wash bottle to dissolve it. Use some of the water to rinse all the substance off the watch glass. Do this at least twice.
3. Stir with a glass rod until all the solid is dissolved, then transfer the solution to the 250ml volumetric flask. Use more water from the wash bottle to rinse out the beaker and the glass rod. Do this at least twice.
4. Add water to just below the line on the 250ml volumetric flask. Add the final drops with a teat pipette to ensure that the bottom of the meniscus is on the line.
5. Put the stopper on the flask and turn the flask over a couple of times to mix the solution.

Number	Learning Intention	Success Criteria
1 *1E*	I will find out that the chemical formula gives the number of atoms of each element in a molecule of a covalent substance *I will find out that the chemical formula of an ionic compound and covalent network tells us the ratio of the elements present.*	I can write correct formulae from models or given molecular pictures
2	I will find out that the chemical formula of an element is simply its symbol	I can state that the chemical formula of an element is simply its symbol
3	I will find out how to work out the formula for 2 element compounds using the Data Book	I can work out the formula for 2 element compounds using the Data Book
4	I will find out how to work out the formula for compounds involving Roman numerals	I can work out the formula for compounds involving Roman numerals
5	I will find out how to work out the formula for compounds with prefixes mono-, di-, tri-, tetra-	I can work out the formula for compounds involving complex ions using brackets where appropriate
6E	I will find out how to work out the formula for compounds involving complex ions using brackets where appropriate	I can work out the formula for compounds involving complex ions using brackets where appropriate
7E	I will find out how to work out the ionic formulae using ion charges where appropriate	I can work out the ionic formulae using ion charges where appropriate

8	I will find out how to write an equation using symbols and formulae from a sentence description or a word equation with sufficient information to have all the reactants and products but not balancing the equation	I can • write a word equation with sufficient information to have all the reactants and products from a sentence description • write an equation using symbols and formulae from a sentence description
9	I will find out how to write balanced equations	I can write balanced equations
10	I will find out that the gram formula mass of any substance is known as one mole	I can to state that the gram formula mass of any substance is known as one mole
11E	I will find out how to calculate the formula mass of a substance	I can • calculate the formula mass of a substance • calculate moles to mass and masses to moles
12E	I will find out how to calculate the concentration of a solution	I can • calculate the concentration of a solution • carry out calculations involving mass from mo1/1 and mass per volume for a requested concentration.

13E	I will find out how to make a standard solution	I can • make a standard solution • carry out the calculations required to make a standard solution