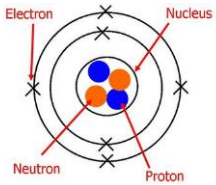
Quantitative Chemistry

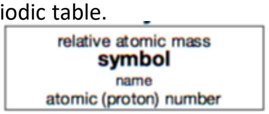
Relative Atomic Mass (RAM)

Remember that atoms are made up of 3 subatomic particles; protons, neutrons and electrons. Only protons and neutrons have mass so the mass of an atom depends on how many protons and neutrons it has.



Because each element has a different number of protons and neutrons the atoms of different elements have different mass. This is called the relative atomic mass.

The RAM of an atom of any element can easily be found from the periodic table.



Relative Formula Mass (RFM)

More often we use elements bonded together in compounds. When more than one atom is bonded together the mass of the molecule is called the relative formula mass (RFM). This can easily be calculated by adding together the RAM of all of the elements in a compound.

Worked Example:

Carbon dioxide has the chemical formula CO_2. It contains:
1 x Carbon atom
2 x Oxygen atoms

1 x C = 1 x 12 = 12
2 x O = 2 x 16 = 32

Now add these numbers together:
RFM CO_2 = 12+ 32 = 44

Percentage Composition

The amount of an element in a compound is called its percentage composition. It can be calculated using the mass of the given element in the compound and the RFM of the compound.

$$\% = \frac{\text{Mass Element}}{\text{RFM}} \times 100$$

Worked Example:

What is the percentage of Mg in MgO?

1. Calculate the RFM
   24 + 16 = 40
2. Determine the mass of Mg in the compound.
   1 X O = 1 x 24 = 24
3. Calculate the percentage
   $= \frac{24}{40} \times 100 = 60\%$

Conservation of Mass

We cannot make or destroy atoms in a chemical reaction, we simply change the order that they are bonded together. Because it is the atoms that give compounds mass then the total mass of reactants at the start of a reaction must equal the total amount of products at the end of a reaction.

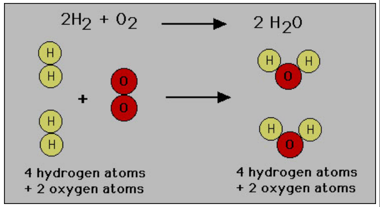
If a reaction is done in a **closed system** (where nothing can get in or out e.g. a container with a lid on) the mass of the reaction will remain constant throughout the reaction.

Mass gained	A gas, e.g. oxygen, has entered the system and has reacted with one of the reactants.
Mass lost	A gas, e.g. carbon dioxide has been produced as a product and left the system

If a reaction is done in an **open system** (where gases can enter or leave) then the mass at may appear to change through the reaction.

Balancing Equations

Since we must always have the same number of atoms at the start and end of a reaction a symbol equation needs to be balanced.

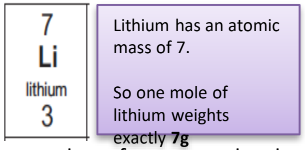


Only big numbers can be added before the formula. Never change the small numbers in the formula as this changes the compound.

Moles

Chemical amounts are measured in moles. It allows us to consider the number of atoms in a given mass and make predictions about the amount of product we can make.

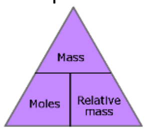
The mass of one mole of an element is the same as its RAM.



The number of atoms, molecules or ions in a mole of a given substance is the **Avogadro constant, N_A**. The value of Avogadro's constant is $\mathbf{6.02 \times 10^{23}}$ per mole. So, 7g of Li contains 6.02×10^{23} atoms of Li.

Because moles and mass are related we can link them with an equation:

$$\text{Moles} = \frac{\text{Mass (g)}}{\text{RFM or RAM}}$$



Worked Example:

How many moles are there in 66g of CO_2?

M_r of CO_2 = 12 + (16 x2) = 44
No. of moles = 66 ÷ 44 = 1.5 mol

Reacting Masses

The masses of reactants and products can be calculated from balanced symbol equations.

Once we have balanced the equation this big number in front of each formula tells us the number of moles of that compound that will react or be made. For example:

$$Mg + 2HCl \rightarrow MgCl_2 + H_2$$

shows that one mole of magnesium reacts with two moles of hydrochloric acid to produce one mole of magnesium chloride and one mole of hydrogen gas. This is called a mole ratio:

1 Mg : 2 HCl : 1 $MgCl_2$: 1 H_2

Using the formula for moles, if we are given a mass of one reactant or product we can work out the mass of the unknown compounds that should be used or will be made.

Worked Example:

How much oxygen is needed to completely react with 12g of carbon?

1. Write a balanced symbol equation:
   $C + O_2 \rightarrow CO_2$
2. Calculate the relative masses of the compounds in the question:
   RAM carbon = 12, RFM O_2 = 32
3. Calculate the number of moles of carbon:
   moles = 12 / 12 = 1
4. Work out the mole ratio in the equation:
   One mole C : One mole O_2
   If we have one mole of C then we need one mole of O_2.
5. Calculate the mass of O_2 needed:
   Mass = moles x RFM
   = 1 x 32
   = 32g

Limiting reactants

In a chemical reaction involving two reactants, it is common to use an excess of one of the reactants to ensure that all of the other reactant is used. The reactant that is completely used up is called the limiting reactant because it limits the amount of products. There will be some of the other reactant left over at the end of the reaction, this is the reactant that is in excess.

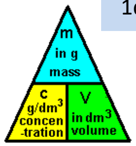
Concentration of solutions

Many chemical reactions take place in solutions. The amount of a substance (solute) in a certain volume of the solution is called its concentration. The more solute in a solution the more concentrated it is.

The concentration of a solution can be measured in mass per volume of solution, the units are grams per dm^3 (g/dm^3).

$$\text{Concentration(g/dm3)} = \frac{\text{Mass (g)}}{\text{Volume (dm3)}}$$

$1dm^3 = 1{,}000cm^3 = 1L$



Take care to convert any kg to g and cm^3 to dm^3.

Worked Example:

What is the concentration in g/dm^3 of a solution of sodium chloride where 30g of sodium chloride is dissolved in $0.2dm^3$ of water?

Concentration = 30 ÷ 0.5 g/dm^3

Chemistry Only:

Yield

The yield of a chemical reaction is the amount that you make. This is usually measured in grams. The maximum yield of any product from a reaction can be calculated using a balanced symbol equation and mole ratios.

Worked Example:
What is theoretical maximum amount of magnesium chloride that can be made from 48g of magnesium?

Step 1: Write a balanced symbol equation.

$Mg + Cl_2 \rightarrow MgCl_2$

Step 2: Calculate the number of moles of Mg being used.

Moles Mg = 48/24 = 2

Step 3: Write down the mole ratio of Mg:$MgCl_2$.

1 Mg : 1 $MgCl_2$

Step 4: Use the ratio to work out how many moles of $MgCl_2$ 2 moles of Mg will make.

2 Mg : 2 $MgCl_2$

Step 5: Use the mole equation to calculate the mass of $MgCl_2$.

Mass = Moles X RFM
Mass = 2 x 95
Mass = 190g

If we know the theoretical maximum yield that can be obtained in a reaction and the actual yield collected from the reaction then we can calculate a percentage yield.

$$\text{Percent Yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100\%$$

The % yield of a reaction will always be less than 100%.

Reasons for lower yield:

- Incomplete reaction
- Reversible reaction
- Impurities in reactants
- Unexpected reactions

Atom Economy

The atom economy is measure of the number of atoms from the reactants that end up **useful products** of the reaction.

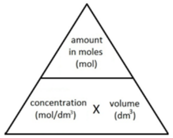
$$\%\text{ atom economy} = \frac{\text{mass of desired product from equation}}{\text{total mass of products from equation}} \times 100$$

The higher the % atom economy then the more economical a reaction is for a company.

Concentrations of Solutions

Concentration can be measure in mol/dm^3 as well as g/dm^3. The principle that we use for the calculation is the same as that we use when we are working with mass, simply swap mass in the equation for moles.

$$\text{Concentration (mol/dm}^3) = \frac{\text{Moles}}{\text{Volume (dm}^3)}$$



Worked Example:
What is the concentration in mol/dm^3 of a solution of sodium chloride where 30g of sodium chloride is dissolved in 0.2dm^3 of water?

Convert mass to moles
Moles = mass/RFM
= 30/58.5
= 0.51

Concentration = Moles ÷ Volume
= 0.51 / 0.2
= 2.55 mol/dm^3

This equation could also be re-arranged and used to calculate the number of moles or volume of a solution of known concentration.

Volumes of Gases

Avagardro's Law states that one mole of any gas **at room temperature and pressure** occupies a volume of **24dm^3**. This can be used to calculate the volume of gas that will be produced in a reaction or the number of moles produced in a reaction.

Volume = Number of moles x 24 (dm^3)

Worked Example:
Calculate the number of moles of H_2 that occupy 6dm^3.

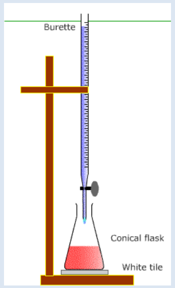
Volume = Number of moles x 24
Number of moles = Volume ÷ 24
= 6 ÷ 24
= 0.25

Required Practical: Titration

You may complete this required practical in the Chemical Changes unit where you are looking at the reaction of acids and alkalis. That is because this a neutralisation reaction. However, titration calculations fit into this unit because we can use them to work out the concentration of a solution if we know the concentration of the other.

Method:

1. Use the pipette and pipette filler to put exactly 25cm^3 sodium hydroxide solution into the conical flask.
2. Clamp the burette vertically in the clamp stand.
3. Making sure the burette tap is closed, carefully fill the burette with dilute sulfuric acid to the 0cm^3 line.
4. Put 5 – 10 drops of methyl orange indicator into the conical flask, swirl to mix.
5. Carefully open the tap so that sulfuric acid flows into the flask at a drop wise rate. Whilst adding acid, constantly swirl the flask and look for a colour change from yellow to red in the indicator.
6. When there are signs that the colour change is close to being permanent, use the tap to slow the drops down. You need be able to shut the tap immediately after a single drop of acid causes the colour to become permanently red.
7. Read the burette scale carefully and record the volume of acid you added.
8. Repeat the whole investigation twice more and record the results of your repeats in the second and third blank spaces.
9. Calculate the mean value for the volume of acid needed to neutralise 25cm^3 of the sodium hydroxide solution.



Errors:

- Meniscus not read at eye level.
- Air bubble in tap of burette.
- Volume recorded inaccurately.

Maths Skills:

Concordant titres have been achieved when you have two or three very similar results. You should then use these to calculate a mean titre, ignoring any anomalous results.

The volume and know concentration of one reagent and the volume of the second reagent can then be used to calculate the unknown concentration.

Worked example:
25.0 cm^3 of a sodium hydroxide solution reacted with a solution of 0.200 mol dm^{-3} hydrochloric acid. Using phenolphthalein indicator for the titration it was found that 15.0 cm^3 of the acid was required to neutralise the alkali. What is the concentration of the sodium hydroxide?

Step 1: Calculate the number of moles of HCl that have reacted.
moles = concentration x volume
moles HCl = 0.200 x (15.0/1000)
= 0.003 mol

Step 2: Use the mole ratio from the equation to determine the number of moles of NaOH that have reacted.
moles HCl = moles NaOH (1 : 1 in equation) so there is 0.003 mol NaOH in 25.0 cm^3.

Step 3: Scale up to 1000cm^3.
25 x 40 = 1000
So
0.003 mol x 40 = 0.12 moles

There will be 0.12 moles in 1000cm3

Concentration = 0.12 mol/dm^3 NaOH