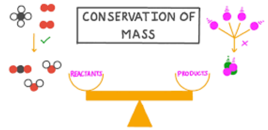
Quantitative chemistry

Conservation of mass and balanced equations

The law of **conservation of mass** states that no atoms are lost or made during a chemical reaction, so the mass of the reactants equals the mass of the products.

Reactants		*Products*
$CaCO_3$	➔	*$CaO + O_2$*
100g	➔	*56g + 44g*



Balanced equations are used to show the number of each type of atom remains the same throughout the reaction.

Numbers are used along with chemical symbols to show the number of each type of atom in a reaction.

A multiplier, represented by a normal script number **in front** of an atom or compound (e.g. 2MgO) multiplies each atom in the compound (2MgO = 2 lots of Mg and 2 lots of O).

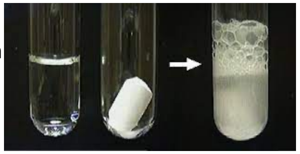
A multiplier, represented by a subscript number **after** an atom (NH_3) multiplies the atom in front of the number only (NH_3 = 1 lot of N and 3 lots of H).

Brackets can be used to show that subscript numbers apply to a section of the formula (e.g. $Ca(OH)_2$ = 1 lot of Ca, 2 lots of O and 2 lots of H).

If no number is present, then there is 1 atom.

Mass changes when a reactant or product is a gas

Some reactions can appear to show a change in mass.



Some reactions **produce gases** which can escape from unsealed systems. An example of this is the thermal decomposition of calcium carbonate which release carbon dioxide.

Some reactions involve **gases as reactants** which may mean that some products have more mass. An example of this is the reaction of magnesium with oxygen forming magnesium oxide.

Use of the amount of a substance in relation to volumes of gases *(separate Chemistry only)*

Equal amounts of moles of gases occupy the same volume under the same conditions of temperature and pressure.

The volume of one mole of any gas at room temperature and pressure (20 °C and 1 atmosphere pressure) is **$24dm^3$.**

The volumes of gaseous reactants and products can be calculated from balanced equations.

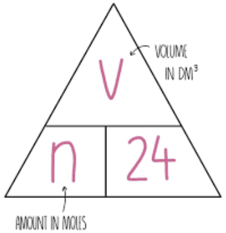
$Mg + 2HCl \rightarrow MgCl_2 + H_2$

Hydrogen is a gas. We can calculate its volume using this equation:

Volume (dm^3) = moles (mol) x $24dm^3$

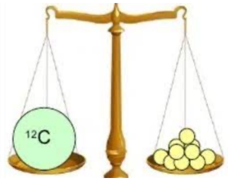
Volume (dm^3) = 1 x 24

Volume (dm^3) = $24dm^3$



Relative formula mass

Relative formula mass (M_r) is the sum of the relative atomic masses of the elements shown in the formula.



Mg=24 *O=16*

MgO = 24 + 16

The relative atomic mass of an element can be found on the periodic table.

In balanced equations the relative formula mass of the reactants and products should be equal:

$2Mg + O_2 \rightarrow 2MgO$

24 + 24 + 16 +16 ➔ 24 + 24 + 16 +16

80 ➔ 80

Percentage by Mass

The percentage and mass of an element can be calculated from a balanced equation:

Percentage of element *= (total relative mass of element ÷ relative formula mass of compound) x 100*

Percentage of oxygen in MgO = (16 ÷ 40) x 100

Percentage of oxygen in MgO = 40%

We can calculate the mass of an element in a compound using the percentage of an element.

%

Mass of an element *= Total mass of a compound x percentage (decimal)*

Mass of oxygen in 50g of MgO = 50g x 0.4

Mass of oxygen in 50g of MgO = 20g

Chemical measurements

Whenever a measurement is made there is always some uncertainty about the result obtained.

Experiments that have been repeated allow us to see uncertainty. We can use the range and mean to measure uncertainty. The greater the spread of data the more uncertainty.

Test	*1*	*2*	*3*	*Mean*
A	*40*	*41*	*39*	*40*
B	*35*	*42*	*44*	*40*

$$uncertainty = \frac{range}{2}$$

The range of results for test A is far less than the range for test B. Test A has less uncertainty.

Quantitative chemistry

Moles *[HT only]*

Chemical amounts are measured in moles. The symbol for the unit mole is mol.

The mass of one mole of a substance is grams is equal to its relative formula mass.

Mg=24 O=16

1 mole of magnesium (Mg) is 24 g

1 mole of oxygen (O_2) is 32 g

One mole of a substance contains the same number of particles, atoms, molecules or ions as one mole of any other substance.

The number of atoms, molecules or ions in a mole of a given substance is the Avogadro constant. The value of the Avogadro constant is 6.02×10^{23} per mole.

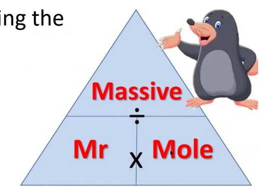
In 1 mole of carbon (C) the number of atoms is equal to the number of molecules in 1 mole of carbon dioxide (CO_2).

We can calculate the number of moles in a given mass using the following equation:

moles = mass (g) ÷ relative formula mass

moles of Mg in 60 g of magnesium = 60 ÷ 24

moles of Mg in 60 g of magnesium = 2.5 mol



Amounts of substance in equations *[HT only]*

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

Moles can be represented in a formula equation by normal script numbers before the element or compound.

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

This shows that 1 mole of Mg reacts with 2 moles of HCl to produce 1 mole of $MgCl_2$ and 1 mole of H_2.

We can use these equations, along with the atomic mass/relative formula mass to calculate the masses of substances.

Mg =24, H = 1, Cl = 35.5

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

$$24g + 73g \rightarrow 95g + 2g$$

We can also calculate masses of reactants or products given a known mass of another reactant or product:

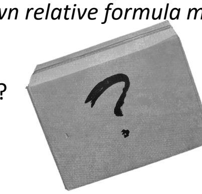
unknown mass = (known mass ÷ known relative formula mass) x unknown relative formula mass

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

How much Mg is needed to make 130g of $MgCl_2$?

unknown mass = (130 ÷ 95) x 24

unknown mass = 32.84g



Concentration of solutions

Many chemical reactions take place in solutions.

The concentration of a solution can be measured in mass (of solute) per given volume of solution e.g. g/dm^3.

A decimetre cubed or dm^3 is 1000ml or 1000 cm^3.

Concentration can be calculated using the following equation:

mass(g) = concentration (g/dm^3) x volume (dm^3)

If 38g of $MgCl_2$ is added to 400ml of water the concentration would be

Don't forget to convert units!

38g = concentration (g/dm^3) x 0.4dm^3

concentration (g/dm^3) = 38 ÷ 0.4

concentration (g/dm^3) = 95g/dm^3

Using moles to balance equations *[HT only]*

Converting the mass of reactants and products to moles can allow us to balance equations.

$$Mg + O_2 \rightarrow MgO$$

If we had - 96g + 64g $\rightarrow$ 160g

moles = mass (g) ÷ relative formula mass

$$(96÷24) + (64÷32) \rightarrow (160÷40)$$

$$4Mg + 2O_2 \rightarrow 4MgO$$

Ratios can be used to calculate simple whole numbers:

$$4Mg + 2O_2 \rightarrow 4MgO$$

4:2:2

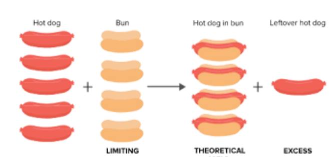
2:1:1

$$2Mg + O_2 \rightarrow 2MgO$$

Limiting reactants *[HT only]*

In a chemical reaction involving 2 reactants it is common to use an excess of one of the reactants to ensure all the other reactant is used.

The reactant that is completely used up is called a limiting reactant because it limits the amount of product.



Quantitative chemistry *(separate Chemistry only)*

Percentage yield

Even though no atoms are gained or lost in a chemical reaction, it is not always possible to obtain the calculated amount of product for the following reasons.

The reaction may not go to completion because it is reversible.

Some of the product may be lost when it is separated from the reaction mixture.

Some of the reactants may react in ways different to the expected reaction .

The amount of product obtained is known as the yield.

The yield you would expect to get is called the maximum theoretical yield.

The amount of product obtained compared to the maximum theoretical yield is called the percentage yield.

%yield = (mass of product actually made ÷ maximum theoretical yield) x 100

$Mg + 2HCl \rightarrow MgCl_2 + H_2$

$24g + 73g \rightarrow 95g + 2g$

This equation shows that we should make 95g of $MgCl_2$ if we use 24g of Mg. If we only make 76g the %yield would be:

%yield = (76 ÷ 95) x 100

%yield = 80%

$$\boxed{\text{PERCENTAGE YIELD} = \frac{\text{ACTUAL YIELD}}{\text{THEORETICAL YIELD}} \times 100}$$

Using concentrations of solutions in mol/dm³

If the volumes of two solutions that <u>react completely</u> are known and the concentration of one solution is known, the concentration of the other solution can be calculated.

$2\,NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2\,H_2O$

25cm³ of H_2SO_4 reacts completely with 22cm³ NaOH. The concentration of the NaOH is 0.105mol/dm³

To calculate the concentration of the H_2SO_4 we use the following formula (where mass represents the mass of solute in solution):

mass(g) = concentration (g/dm³) x volume (dm³)

Calculating 2NaOH

mass = 0.105 x 0.022

mass = 0.00231g

There is twice as many moles of NaOH as there is of H_2SO_4 so we divide this figure by 2

mass = 0.001155g

Calculating H_2SO_4

mass(g) = concentration (g/dm³) x volume (dm³)

0.001155 = concentration (g/dm³) x 0.025

concentration (g/dm³) = 0.001155 ÷ 0.025

concentration (g/dm³) = 0.0462g/dm³

4 mol/dm³

Atom economy

The atom economy is a measure of the amount of starting materials that ended up as useful products.

A high atom economy is desirable for environmental and economic reasons.

Atom economy can be calculated using the formula:

Atom economy = (Relative formula mass of the desired product ÷ sum of relative formula masses of all reactants) x 100

Mg =24, H = 1, Cl = 35.5

$Mg + 2HCl \rightarrow MgCl_2 + H_2$

If $MgCl_2$ is the desired product then

Atom economy = (95 ÷ 97) x 100

Atom economy = 97.94%

Particular reaction pathways can be selected because of the atom economy, yield, equilibrium position and usefulness of the by-products.

$$\boxed{\%\ \text{ATOM ECONOMY} = \frac{M_r\ \text{OF DESIRED PRODUCT}}{M_r\ \text{OF TOTAL PRODUCTS}} \times 100}$$