1.24 Calculations and Chemical Reactions

Converting quantities between different substances using a balanced equation

A balanced chemical equation tells us the number of particles of a substance which react with another substance. It also therefore tells us the ratios in moles in which these substances react.

Eg	$2H_2$	+	O_2	→	$2\ H_2O$
	2 moles H_2		1 mole O_2		2 moles H_2O

All calculations involving chemical reactions will need quantities given to be converted into amount in moles. Then the balanced equation can be used to identify reacting mole ratios

$$N_2 + \mathbf{3}H_2 \rightarrow \mathbf{2}NH_3$$

The balancing (stoichiometric) numbers are the mole ratios
e.g. **1** mol of N_2 reacts with **3** mol of H_2 to produce **2** mol of NH_3

Most calculations will only involve two substances from the reaction and it is only necessary to identify the mole reacting ratio between those two substances.

So if a reaction involved 0.5 mol of N_2 we can say it would react with 1.5 mol of H_2 using the 1 N_2 :3 H_2 ratio

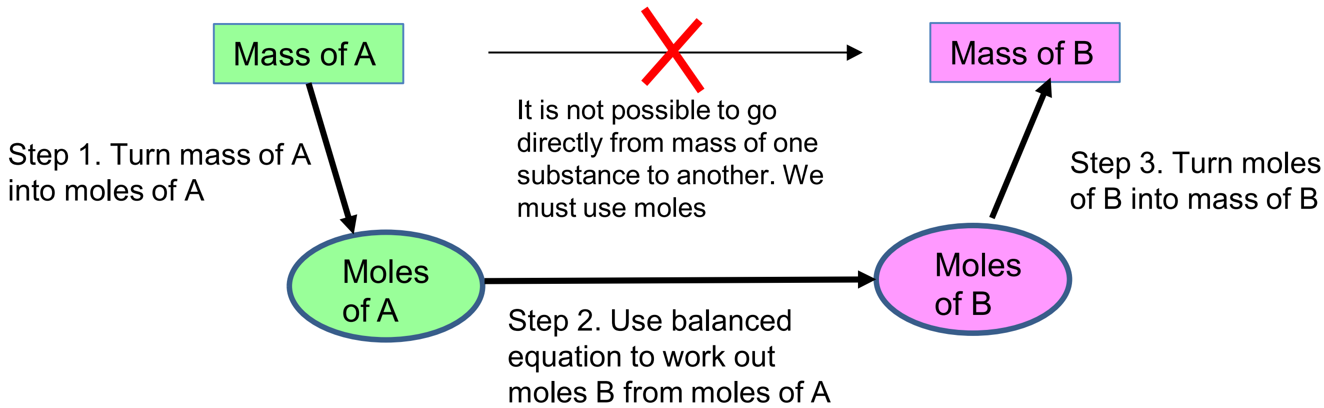
Or if 0.4 moles of NH_3 was produced we would need 0.6 mol of H_2 using the 2 NH_3 :3 H_2 ratio

Reacting Mass Questions

When doing calculations involving masses of different substances in a chemical reactions, to convert from mass of A to mass of substance B we must use moles.

A+B → products   A+ other reactant → B

A & B can be any two reactants or products



Example 1 Calculate the mass of carbon dioxide produced from heating 5.50 g of sodium hydrogencarbonate.
$2NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$

Step 1: calculate amount, in mol, of sodium hydrogencarbonate
amount = mass / *Mr*
= 5.50 /84.0
= 0.0655 mol

Step 2: use balanced equation to give amount in mol of CO_2
2 moles $NaHCO_3$: 1 moles CO_2
So 0.0655 HNO_3 : 0.0328mol CO_2

Step 3: calculate mass of CO_2
Mass = amount x *Mr*
= 0.0328 x 44.0
=1.44g

Remember stoichiometric balancing numbers are not used to calculate *M*r. The *Mr* of $NaHCO_3$ is always 84.0 whatever the balancing number in front of it

Reacting Mass Questions

1.1) Calculate the mass of TiO_2 made from reacting 10.0g of $TiCl_4$ with water.
$TiCl_4(l) + 2\,H_2O(l) \rightarrow TiO_2(s) + 4\,HCl(aq)$

1.2) Calculate the mass of calcium chloride formed when 0.500 g of calcium reacts with hydrochloric acid.
$Ca + 2\,HCl \rightarrow CaCl_2 + H_2$

1.3) Calculate the mass of carbon monoxide needed to reduce 3.00 kg of iron oxide to iron.
$Fe_2O_3 + 3\,CO \rightarrow 2\,Fe + 3\,CO_2$

1.4) Calculate the mass of F_2 needed to produce 150 g of C_4F_{10}.
$C_4H_{10} + 10\,F_2 \rightarrow C_4F_{10} + 10\,HF$

1.5) Calculate the mass of NO produced from reacting 0.500 g of CuS with concentrated nitric acid.

$3\,CuS + 8\,HNO_3 \rightarrow 3\,CuSO_4 + 8\,NO + 4\,H_2O$

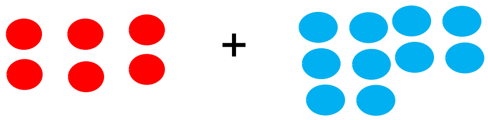
Limiting and excess reactants

If a question gives masses of two of more reactants we will need to consider whether one is in excess. In most cases when there are two reactants, after they have reacted we will be left with some of one reactant. This is the amount that is in excess. Students often find this a complex idea to understand.

Let us consider the reaction of A and B reacting with a ration of 1A:2B

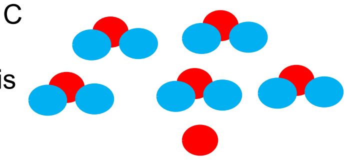
$$A + 2B \rightarrow C$$

If we had 6 moles of A and 10 of B, which is in excess and how much C would be produced?



$\rightarrow$?

We could make 5 moles of C and we would have 1 mole of A left over as excess. B is what we call the limiting reactant



So if given masses of two reactants then it is necessary to work out moles of both substances and do the above exercise to work out which one is limited and which one is in excess.

Example 2 Calculate the maximum mass of titanium that could be produced from reacting 100 g of $TiCl_4$ with 80 g of sodium.

$$TiCl_4 + 4\ Na \rightarrow 4\ NaCl + Ti$$

Step 1: work out amount, in mol, $TiCl_4$
amount = mass / *Mr*
= 100 /189.9
= 0.527 mol

Step 1: work out amount, in mol, Na
amount = mass / *Mr*
= 80/23.0
= 3.48 mol

Step 2 use balanced equation to work out which reactant is in excess
Using 1$TiCl_4$:4 Na ratio we can see that 0.527mol of $TiCl_4$ should react with 2.108 mol of Na. We actually have 3.48 mole of Na which is an excess of 1.372 moles. We can complete calculation using the limiting reactant of $TiCl_4$

Step 3: use balanced equation to work out amount in mol of Ti formed
1 mol $TiCl_4$: 1 mole Ti
So 0.527mol $TiCl_4$ produces 0.527 mole Ti

Step 4: work out mass of Ti formed
Mass = amount x *Mr*
= 0.527 x 47.9
=25.24 g

2.1) Calculate the maximum mass of iron sulfide that can be produced from 20.0 g of iron and 30.0 g of sulfur.

$$Fe + S \rightarrow FeS$$

2.2) Calculate the maximum mass of ammonia that can be produced from 400 g of ammonium chloride and 100 g of calcium oxide.

$$2\ NH_4Cl + CaO \rightarrow CaCl_2 + H_2O + 2\ NH_3$$

2.3) Calculate the maximum mass of aluminium chloride that can be produced from 25.0 g of aluminium and 50.0 g of HCl.

$$2\ Al + 6\ HCl \rightarrow 2\ AlCl_3 + 3\ H_2$$

2.4) Calculate the maximum mass of iron (**III**) chloride that can be produced from 50.0 g of Fe and 100g of chlorine gas.

$$2\ Fe + 3\ Cl_2 \rightarrow 2\ FeCl_3$$

2.5) Calculate the maximum mass of phosphorus that can be produced from reacting 100 g of $Ca_5F(PO_4)_3$, 100g of SiO_2 and 100g of carbon.

$$2\ Ca_5F(PO_4)_3 + 9\ SiO_2 + 15\ C \rightarrow 9\ CaSiO_3 + CaF_2 + 15\ CO + 6\ P$$

Calculations involving masses, solutions and gases

Commonly in questions converting between quantities of substances reacting we will use more than just mass data. We might have the volume and concentration of a solution, or the volume of a gas. We need to adapt our existing method or reacting masses to include other quantities. Any of the equations below can be used to convert quantities into moles.

1. For pure solids, liquids and gases

$$\text{amount} = \frac{\text{mass}}{\text{MolarMass}}$$

Unit of mass: grams
Unit of amount : mol

2. For Gases

Gas volume (dm^3)= amount x 24

This equation give the volume of a gas at room pressure (1atm) and room temperature 25°C.

Or use the ideal gas equation to work out gas volumes at other temperatures and pressures

$$PV = nRT$$

3. For solutions

$$\text{Concentration} = \frac{\text{amount}}{\text{volume}}$$

Unit of concentration: mol dm^{-3} or M
Unit of volume: **dm^3**

General method

Step 1:
Use one of the above equations to convert any given quantity into amount in mol
Mass→ amount
Volume of gas → amount
Conc and vol of solution → amount

→

Step 2:
Use balanced equation to convert amount in mol of initial substance into amount in mol of second substance

→

Step 3
Convert amount, in mol, of second substance into quantity question asked for using relevant equation
e.g. amount, *Mr* → mass
amount gas → vol gas
amount, vol solution → conc

Example 3: Calculate the mass of copper that reacts completely with 150 cm^3 of 1.60 mol dm^{-3} nitric acid.
$3 Cu + 8 HNO_3 \rightarrow 3Cu(NO_3)_2 + 2 NO + 4 H_2O$

Step 1: work out moles of nitric acid
amount = conc x vol
= 1.6 x 0.15
= 0.24 mol

Step 2: use balanced equation to give moles of Cu
8 moles HNO_3 : 3 moles Cu
So 0.24 HNO_3 : 0.09 (0.24 x $^3/_8$) mol Cu

Step 3: work out mass of Cu
mass = amount x *Mr*
= 0.09 x 63.5
=5.71 g

Example 4: Calculate the total volume of gas produced in dm^3 at 333 K and 100 kPa when 0.651 g of magnesium nitrate is heated.
$2 Mg(NO_3)_{2\,(s)} \rightarrow 2 MgO_{(s)} + 4 NO_{2\,(g)} + O_{2\,(g)}$

Step 1: work out moles of magnesium nitrate
amount = mass / *Mr*
= 0.651 / 148.3
= 0.00439 mol

Step 2: use balanced equation to give moles of gas produced
2 moles $Mg(NO_3)_2$: $4NO_{2\,(g)} + O_{2\,(g)}$ i.e. 5 moles of gas
So 0.00439 $Mg(NO_3)_2$: 0.01098(0.00439 x $^5/_2$) moles gas

Step 3: work out volume of gas

Volume = nRT/P
= (0.01098 x 8.31 x 333)/ 100000
= 0.000304m^3
= 0.303 dm^3

Questions involving masses, solutions and gases

3.1) Hydrogen can be made by the reaction of hydrochloric acid with magnesium according to the equation
$2HCl + Mg \rightarrow MgCl_2 + H_2$
Calculate the mass of hydrogen formed when 200cm^3 of hydrochloric acid of concentration 2.50 mol dm^{-3} reacts with an excess of magnesium.

3.2) Lead(II) nitrate can be produced by the reaction between nitric acid and lead(II) oxide as shown by the equation below.
$PbO + 2HNO_3 \rightarrow Pb(NO_3)_2 + H_2O$
An excess of lead(II) oxide reacted with 250cm^3 of 1.25 mol dm^{-3} nitric acid.
Calculate the maximum mass of lead(II) nitrate which could have been obtained.

3.3) Calculate the volume, in cm^3, of 1.50 mol dm^{-3} hydrochloric acid required to react completely with 1.20 g of magnesium hydroxide. $Mg(OH)_2(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + 2H_2O(l)$

3.4) A volume of 150cm^3 of 1.75 mol dm^{-3} nitric acid was completely reacted with copper metal. The equation for the reaction is shown below. Calculate the mass of copper that would react completely with this amount of nitric acid.

$$3Cu + 8HNO_3 \rightarrow 3Cu(NO_3)_2 + 2NO + 4H_2O$$

3.5) A sample of sodium hydrogencarbonate was heated until completely decomposed. The CO_2 formed in the reaction occupied a volume of 352 cm^3 at 1.00×10^5 Pa and 298 K.
Calculate the mass of the $NaHCO_3$ that has decomposed.

$$2NaHCO_3(s) \rightarrow Na_2CO_3(s) + CO_2(g) + H_2O(g)$$

3.6) Oxygen may be prepared by the decomposition of hydrogen peroxide, H_2O_2, as shown in the equation.
$2\,H_2O_2(aq) \rightarrow 2\,H_2O(l) + O_2(g)$
A 160 cm^3 sample of 2.68 mol dm^{-3} aqueous hydrogen peroxide was decomposed completely.
Calculate the mass and volume of oxygen gas produced at 25 ^{o}C and 100 kPa.

3.7) Phosphine, PH_3, and oxygen can react to form phosphoric acid, H_3PO_4, as shown in the equation below.
$PH_3 + 2\,O_2 \rightarrow H_3PO_4$
An excess of oxygen was mixed with 2.70 g of phosphine in a sealed container and allowed to react.
Calculate the mass of phosphoric acid formed in this reaction.

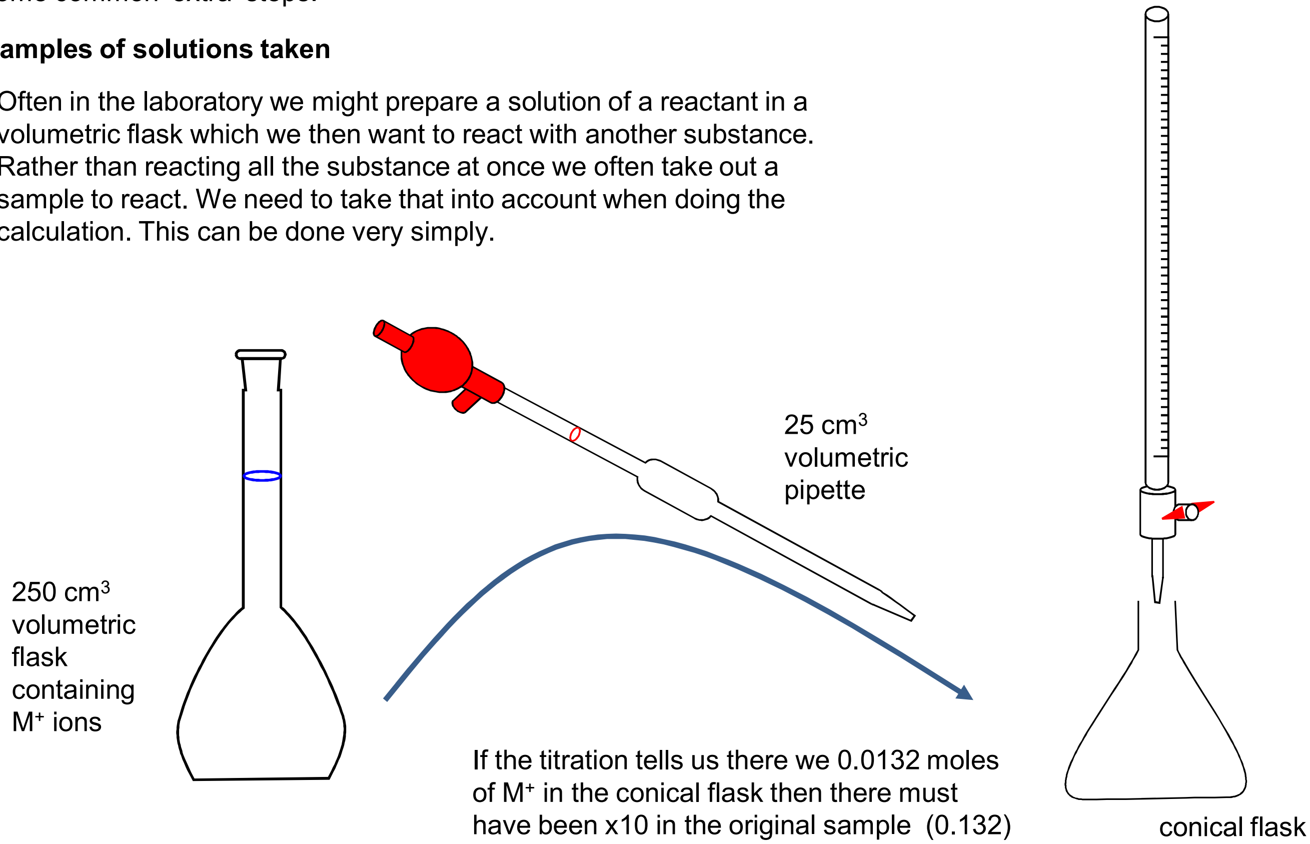
3.8) Ammonium sulfate reacts with sodium hydroxide to form ammonia, sodium sulfate and water as shown in the equation below.
$(NH_4)_2SO_4(s) + 2\,NaOH(aq) \rightarrow 2\,NH_3(g) + Na_2SO_4(aq) + 2\,H_2O(l)$
A 3.24 g sample of ammonium sulfate reacted completely with 39.70 cm^3 of a sodium hydroxide solution.
Calculate the concentration, in mol dm^{-3}, of the sodium hydroxide solution used.

Questions involving samples being taken

There are many variations on these calculations. It is not possible to learn an exact method for every type of calculation you could ever meet. You need to be able to go back to the chemistry and picture what is happening. Sometimes it is actually a good idea to draw out what is happening. Let's look at some common 'extra' steps.

Samples of solutions taken

Often in the laboratory we might prepare a solution of a reactant in a volumetric flask which we then want to react with another substance. Rather than reacting all the substance at once we often take out a sample to react. We need to take that into account when doing the calculation. This can be done very simply.



If the titration tells us there we 0.0132 moles of M^+ in the conical flask then there must have been x10 in the original sample (0.132) because we removed a tenth of the solution with the pipette.

Example 5. An unknown metal carbonate reacts with hydrochloric acid according to the following equation.
$M_2CO_3(aq) + 2HCl(aq) \rightarrow 2MCl(aq) + CO_2(g) + H_2O(l)$
A 3.96 g sample of M_2CO_3 was dissolved in distilled water to make 250 cm^3 of solution. A 25.0 cm^3 portion of this solution required 32.8 cm^3 of 0.175 mol dm^{-3} hydrochloric acid for complete reaction.
Calculate the *Mr* of M_2CO_3 and identify the metal M.

1. Calculate the number of moles of HCl used.

   amount = conc x vol
   = 0.175 x 0.0328
   = 0. 00574 mol

2. Work out number of moles of M_2CO_3 in 25.0 cm^3 put in conical flask.

   use balanced equation to give moles of M_2CO_3
   2 mol HCl : 1 mol M_2CO_3
   So 0. 00574 HCl : 0.00287 moles M_2CO_3

3. Calculate the number of moles M_2CO_3 acid in original 250 cm^3 of solution

   Moles in 250cm^3 = 0.00287 x10
   = 0.0287

4. work out the *Mr* of M_2CO_3

   Mr = mass / amount
   = 3.96/ 0.0287 = 138.0

5. Work out *Ar* of M = $\frac{(138-12-16x3)}{2}$

   Ar of M = 39

   M = potassium

Questions involving samples being taken

4.1) An acid, H_2A, reacts with sodium hydroxide as shown in the equation below.
$H_2A(aq) + 2NaOH(aq) \rightarrow 2Na^+(aq) + A^{2-}(aq) + 2H_2O(l)$
A solution of this acid was prepared by dissolving 2.02 g of H_2A in water and making the volume up to 250 cm^3 in a volumetric flask.
A 25.0 cm^3 sample of this solution required 22.80 cm^3 of 0.150 mol dm^{-3} aqueous NaOH for complete reaction. Calculate the relative molecular mass, M_r, of H_2A

4.2) Sodium carbonate forms several hydrates of general formula $Na_2CO_3.xH_2O$. A 2.98 g sample of one of these hydrates was dissolved in water and the solution made up to 250cm^3. In a titration, a 25.0 cm^3 portion of this solution required 28.3 cm^3 of 0.170 mol dm^{-3} hydrochloric acid for complete reaction. The equation for this reaction is shown below.
$Na_2CO_3 + 2\,HCl \rightarrow 2\,NaCl + H_2O + CO_2$
Calculate the relative molecular mass, M_r of the hydrated sodium carbonate and therefore the value of x.

4.3) 10.8 g of a solid monoprotic acid, HA was dissolved in water and made up to 250 cm^3 in a volumetric flask 25.0 cm^3 portions of this were titrated against 0.200 mol dm^{-3} sodium hydroxide, requiring 23.0 cm^3. Calculate the relative molecular mass, M_r of the acid.

4.4) A 20.0 g sample of a domestic cleaning chemical containing ammonia (NH_3) was dissolved in water and the solution was made up to 500cm^3 in a volumetric flask. A 25.0 cm^3 portion of this solution was then reacted with 26.8 cm^3 of 0.20 mol dm^{-3} sulfuric acid. Calculate the percentage by mass of ammonia in the cleaning solution

$$2\,NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$$

4.5) 1.70 g of a metal carbonate, M_2CO_3, was dissolved in water and the solution was made up to 250cm^3 in a volumetric flask. 25.0 cm^3 of this solution was then reacted with 24.6 cm^3 of 0.100 mol dm^{-3} hydrochloric acid. Calculate the relative formula mass of M_2CO_3 and hence the relative atomic mass and identity of the metal M.

4.6) 1.00 cm^3 of concentrated hydrochloric acid was transferred with a graduated pipette to a 100 cm^3 volumetric flask. The volume was made up to 100 cm^3 with distilled water.
A 10.0 cm^3 portion of the diluted solution from the volumetric flask was titrated by NaOH and was neutralised by 24.35 cm^3 of sodium hydroxide of concentration 0.0500 mol dm^{-3}. Calculate the concentration of the original concentrated hydrochloric acid in mol dm^{-3}.

Calculations involving two or more reactions

One type of question is where there is a series of reactions when one occurs after the other. The product of the first reaction becomes the reactant of the second reaction.

2 $Mg(NO_3)_2 \rightarrow$ **2**$MgO + 4NO_2 + O_2$

If there was 0.1mol of $Mg(NO_3)_2$ then it would produce 0.1 mol of MgO in the first reaction (Using the 2 $Mg(NO_3)_2$: 2 MgO ratio)

MgO + **2** $HCl \rightarrow MgCl_2 + H_2O$

Then all the 0.1 mol of MgO made in the first reaction would react with 0.2 mol of HCl in the second reaction (Using the 1 MgO: 2HCl ratio)

Remember the balancing numbers give the mole ratios for that equation. Don't try to link balancing numbers in one reaction to the balancing numbers in the second.

5.1) A 2.23g sample of magnesium nitrate was fully decomposed.
$2\ Mg(NO_3)_2 \rightarrow 2\ MgO + 4\ NO_2 + O_2$
The magnesium oxide, produced was reacted with hydrochloric acid.
$MgO + 2\ HCl \rightarrow MgCl_2 + H_2O$
This sample of magnesium oxide required 33.2cm^3 of hydrochloric acid for complete reaction.
Calculate the concentration, in mol dm^{-3}, of the hydrochloric acid.

5.2) Sodium carbonate is manufactured in a two-stage process as shown by the equations below.
$NaCl + NH_3 + CO_2 + H_2O \rightarrow NaHCO_3 + NH_4Cl$
$2\ NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$
Calculate the maximum mass of sodium carbonate which could be obtained from 600 g of sodium chloride.

5.3) The chloride of an element **X** reacts with water according to the following equation.
$XCl_4(l) + 2\ H_2O(l) \rightarrow XO_2(s) + 4\ HCl\ (aq)$
A 1.436 g sample of XCl_4 was added to water. The solid XO_2 was removed by filtration and the resulting solution was made up to 250 cm^3 in a volumetric flask. A 25.0 cm^3 portion of this solution was titrated against a 0.120 mol dm^{-3} solution of sodium hydroxide, of which 22.3 cm^3 were required to reach the end point.
$NaOH + HCl \rightarrow NaCl + H_2O$
Calculate the relative molecular mass, *M*r, of XCl_4 and then deduce the relative atomic mass, *A*r, of element **X** and its identity.

5.4) A old bronze coin of mass 2.15 g containing copper and tin was dissolved in concentrated nitric acid and the NO gas escaped through boiling. The equation below shows the reaction of the copper with the acid

$$3\ Cu\ (s) + 8\ HNO_3\ (aq) \rightarrow 3\ Cu(NO_3)_2\ (aq) + 2\ NO\ (g) + 4\ H_2O\ (l)$$

The solution was diluted with water to make up to 250 cm^3. 25 cm^3 portions were neutralised and added to excess potassium iodide solution. Only the copper ions reacted with the iodide ions to produce iodine.
Equation for reaction $2\ Cu^{2+}\ (aq) + 4\ I^-\ (aq) \rightarrow 2\ CuI\ (s) + I_2(aq)$

The liberated iodine was then titrated with sodium thiosulfate. The iodine required 30.40 cm^3 of 0.100 mol dm^{-3} sodium thiosulfate ($Na_2S_2O_3$) to react.

$$I_2\ (aq) + 2\ S_2O_3{}^{2-}(aq) \rightarrow 2\ I^-\ (aq) + S_4O_6{}^{2-}\ (aq)$$

Calculate the percentage of copper in the brass coin.

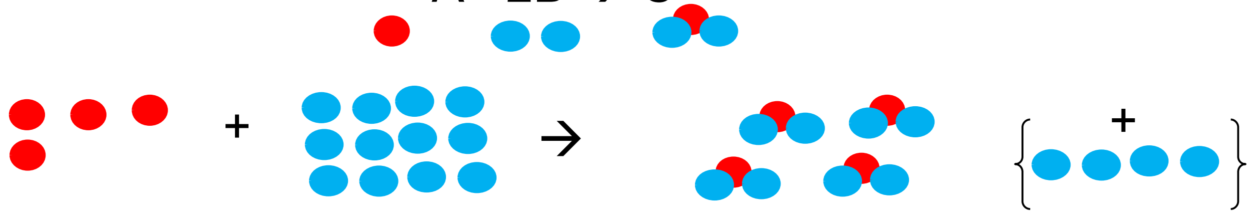
5.5) The amount of ozone in the atmosphere may be determined by passing air through a solution of acidified potassium iodide to form Iodine in the following reaction $O_3 + 2I^- + 2H^+ \rightarrow O_2 + H_2O + I_2$
The amount of iodine formed can be determined by titration with a solution of sodium thiosulfate of known concentration in the following reaction $I_2 + 2S_2O_3{}^{2-} \rightarrow 2I^- + S_4O_6{}^{2-}$
In an experiment to determine the amount of ozone in air, 100 m^3 of air was bubbled through 100 cm^3 of a solution containing an excess of acidified potassium iodide. The resulting solution was titrated against a solution of sodium thiosulfate of concentration 0.0167 mol dm^{-3}. The volume of sodium thiosulfate solution required for the complete reaction was 24.80 cm^3.
Calculate the amount in moles of ozone in the 100 m^3 sample and calculate the volume of ozone in m^3. (assuming the volume is measured at room temperature and pressure). What percentage by volume of air is ozone?

The second type of calculation involving two different reactions occurs when the first reaction leaves an excess reactant. The second reaction then involves the reaction of the excess reactant.

Think about the following series of reactions with A reacting with excess B in a first reaction. Then the remaining B reacts in a second reaction with reactant D. (equations below)

If we had 4 moles of A and 12 of B, which is in excess and how much B would be left over?

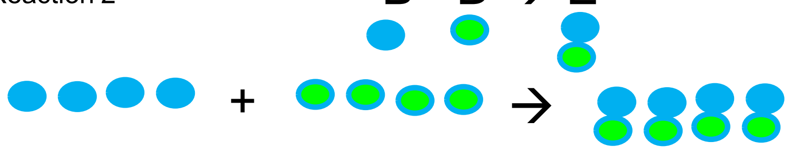
Reaction 1 $\quad A + 2B \rightarrow C$



4 moles of B left over

The 4 moles of B left over would react with 4 moles of D

Reaction 2 $\quad B + D \rightarrow E$

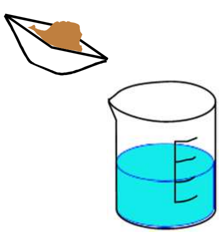


Now try this problem. If 17 moles of B reacted with an unknown quantity of A and the unreacted B reacted with 3 moles of D. How many moles of A would there have been? *The answer is 7*

This logic is used to solve a type of calculation we call a **back titration**.

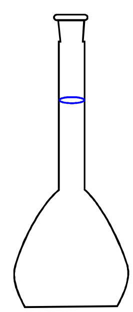
Example 6: 950 mg of impure calcium carbonate tablet was crushed. 50.0 cm^3 of 1.00 mol dm^{-3} hydrochloric acid, an excess, was then added and the mixture was transferred to a volumetric flask. The volume was made up to exactly 100 cm^3 with distilled water. 10.0 cm^3 of this solution was titrated with 11.1cm^3 of 0.300 mol dm^{-3} sodium hydroxide solution.
Calculate the percentage of $CaCO_3$ by mass in the tablet.

950 mg of impure calcium carbonate

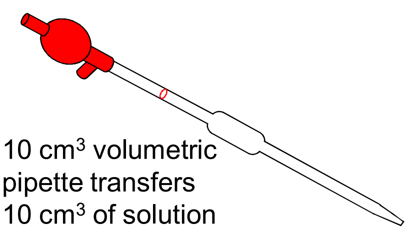


50.0 cm^3 of 1.00 mol dm^{-3} HCl

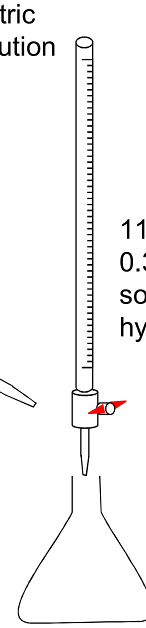
This reaction occurs
$CaCO_3(s) + 2\,HCl\,(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$
All the $CaCO_3$ is reacted some HCl is left over



100 cm^3 volumetric flask containing unreacted HCl made up to 100cm^3 distilled water.



10 cm^3 volumetric pipette transfers 10 cm^3 of solution containing unreacted HCl



11.1cm^3 of 0.300 mol dm^{-3} sodium hydroxide

conical flask

This reaction occurs
$NaOH + HCl\,(aq) \rightarrow NaCl\,(aq) + H_2O(l)$
The NaOH reacts with left over HCl in 10cm^3 solution

The calculation works backwards using the titration results first.

950 mg of impure calcium carbonate tablet was crushed. 50.0 cm^3 of 1.00 mol dm^{-3} hydrochloric acid, an excess, was then added and the mixture was transferred to a volumetric flask. The volume was made up to exactly 100 cm^3 with distilled water. 10.0 cm^3 of this solution was titrated with 11.1cm^3 of 0.300 mol dm^{-3} sodium hydroxide solution.
Calculate the percentage of $CaCO_3$ by mass in the tablet.

1. Calculate the amount in moles of sodium hydroxide used.

amount = conc x vol
= 0.30 x 0.0111
= 0. 00333 mol

2. Work out the amount in moles of hydrochloric acid that reacted with the NaOH

$NaOH + HCl(aq) \rightarrow NaCl\ (aq) + H_2O(l)$

use balanced equation to give moles of HCl
1 mol NaOH : 1 mol HCl
So 0.00333 mol NaOH : 0.00333 mol HCl

This is the amount of moles of HCl that were in the conical flask and hence in the 10cm^3 pipette

3. Calculate the amount in moles of hydrochloric acid left in 100 cm^3 of solution.

Moles in 100cm^3 = 0.00333 x10
=0.0333 mol

The 10cm^3 pipetted sample came from the 100cm^3 volumetric flask so to work out the amount of moles in the flask multiply by 10

4. Calculate the amount in moles of HCl that reacted with the indigestion tablet.

In original HCl 50.0 cm^3 of 1.00 mol dm^{-3} there is 0.05 mol

moles of HCl that reacted with the indigestion tablet. =0.05 -0.0333
=0.0167mol

The amount of moles of HCl that reacted the $CaCO_3$ is the difference between the total amount of moles of HCl at the start and the moles of HCl left over at the end of this reaction.

5 Use balanced equation to give moles of $CaCO_3$ that reacted with the HCl
$CaCO_3(s) + 2\ HCl\ (aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$
2 mol HCl : 1 mol $CaCO_3$
So 0.0167 HCl : 0.00835 moles $CaCO_3$

6. work out the mass of $CaCO_3$ in original tablet

mass= amount x *Mr*

= 0.00835 x 100.1 = 0.836 g

7. Calculate percentage of $CaCO_3$ by mass in the tablet = 0.836/0.950 x100

= 88.0 %

Divide the mass of calcium carbonate that reacted by the mass of the original impure tablet X100

Back Titration questions

6.1) A 0.132 g of an impure sample of quicklime was dissolved in 50.0 cm^3 of hydrochloric acid, concentration 0.100 mol dm^{-3}. The excess hydrochloric acid was titrated with sodium hydroxide solution, concentration 0.100 mol dm^{-3}, and 17.7 cm^3 was needed to just neutralize the acid.
The equations for the reactions involved are shown below.
$CaO(s) + 2HCl\ (aq) \rightarrow CaCl_2(aq) + H_2O(l)$
$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$
Calculate the percentage purity of the calcium oxide.

6.2) The amount of sulfur dioxide in the air can be measured by bubbling a known volume of air through iodine solution. Sulfur dioxide converts the iodine to iodide ions according to the following equation.
$SO_2(g) + I_2(aq) + 2H_2O(l) \rightarrow SO_4^{2-}(aq) + 4H^+(aq) + 2I^-(aq)$
In an experiment, 75 m^3 of air were passed through 50 cm^3 of iodine, of concentration 0.0200 mol dm^{-3}. The remaining iodine was titrated with sodium thiosulfate solution and reacted with 14.70 cm^3 of sodium thiosulfate, concentration 0.100 mol dm^{-3}.
$I_2\ (aq) + 2S_2O_3^{\ 2-}(aq) \rightarrow 2I^-\ (aq) + S_4O_6^{\ 2-}\ (aq)$

Calculate the moles of sulfur dioxide that were in the original 75 m^3 sample.

6.3) 9.8 g of a indigestion remedy containing calcium carbonate was reacted with 100 cm^3 of 2.00 mol dm^{-3} hydrochloric acid. (Only the calcium carbonate in the remedy reacts). The resulting solution was made up to 250 cm^3 with water in a volumetric flask. A 25.0 cm^3 portion of this solution required 28.9 cm^3 of 0.200 mol dm^{-3} sodium hydroxide for neutralisation. Calculate the percentage by mass of the calcium carbonate in the indigestion remedy.
The equations for the reactions involved are shown below.
$CaCO_3(s) + 2\ HCl\ (aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$
$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$

6.4) 1.13 g of an impure sample of calcium hydroxide was dissolved in 50.0 cm^3 of hydrochloric acid, concentration 1.00 mol dm^{-3}. The resulting solution was made up to 250 cm^3 with water in a volumetric flask. A 25.0 cm^3 portion of this solution required 30.7 cm^3 of 0.100 mol dm^{-3} sodium hydroxide for neutralisation.
The equations for the reactions involved are shown below.
$Ca(OH)_2\ (s) + 2\ HCl\ (aq) \rightarrow CaCl_2(aq) + 2H_2O(l)$
$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$
Calculate the percentage purity of the calcium hydroxide.

6.5) 1.50g of Bordeaux mixture containing a mixture of calcium hydroxide ($Ca(OH)_2$) and copper(II) sulfate-5-water ($CuSO_4.5H_2O$) was added to 25.0 cm^3 of hydrochloric acid, concentration 2.00 mol dm^{-3} . The calcium hydroxide in the mixture will neutralise some of the acid. The resulting solution was made up to 250 cm^3 with water in a volumetric flask. A 25.0 cm^3 portion of this solution required 26.7 cm^3 of 0.100 mol dm^{-3} sodium hydroxide for neutralisation. Calculate the percentage, by mass, of calcium hydroxide in the sample of Bordeaux mixture.

6.6) Dolomite is a carbonate-containing mineral with formula $CaX(CO_3)_2$ where X is a metal ion.
The carbonate ions in Dolomite react with acid. The ionic equation for the reaction between hydrogen ions and carbonate ions is shown.
$2\ H^+(aq) + CO_3^{2-}(aq) \rightarrow CO_2(g) + H_2O(l)$
A 6.00 g sample of dolomite is dissolved in 35.0 cm^3 of 5.00 mol dm^{-3} hydrochloric acid, which is an excess. The resulting solution is made up to 100 cm^3 in a volumetric flask, using distilled water. 10.0 cm^3 portions of this solution are titrated against sodium hydroxide. 22.40 cm^3 of 0.200 mol dm^{-3} NaOH is required for neutralisation. Calculate the relative formula mass of $CaX(CO_3)_2$ and hence the relative atomic mass and identity of the metal ion X

% Yield

$$\text{percentage yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$

% yield in a process can be lowered through incomplete reactions, side reactions, losses during transfers of substances, losses during purification stages.

Example 7: 25g of Fe_2O_3 was reacted and it produced 10g of Fe. Calculate the percentage yield.

$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$

First calculate the maximum/theoretical mass of Fe that could be produced.

Step 1: work out amount in mol of Iron oxide
amount = mass / *M*r
=25 / 159.6
= 0.1566 mol

Step 2: use balanced equation to give moles of Fe
1 moles Fe_2O_3 : 2 moles Fe
So 0.1566 Fe_2O_3 : 0.313moles Fe

Step 3: work out mass of Fe
Mass = amount x *M*r
= 0.313 x 55.8
=17.48g

% yield = (actual yield/theoretical yield) x 100
= (10/ 17.48) x 100
=57.2%

7.1) 10.0 g of $CaCO_3$ of was reacted with H_2SO_3. The reaction was incomplete and only 10.7g of $CaSO_3$ was formed. Calculate the percentage yield of the reaction.

$H_2SO_3 + CaCO_3 \rightarrow CaSO_3 + H_2O + CO_2$

7.2) 5.70g of Copper metal was reacted with HNO_3. The reaction was incomplete and only 14.80g of $Cu(NO_3)_2$ was formed. Calculate the percentage yield of the reaction.

$3Cu + 8HNO_3 \rightarrow 3Cu(NO_3)_2 + 2NO + 4H_2O$

7.3) 5.78 g of magnesium carbonate were added to an excess of sulfuric acid. The following reaction occurred.
$MgCO_3 + H_2SO_4 \rightarrow MgSO_4 + CO_2 + H_2O$
Calculate the actual mass of $MgSO_4$ produced in this reaction assuming a 85% yield.

7.4) The reaction from ethanoic acid (CH_3COOH) has a percentage yield of 82%. Calculate the minimum mass of butane needed to actually produce 10.2g of CH_3COOH

$2C_4H_{10} + 5O_2 \rightarrow 4CH_3COOH + 2H_2O$

7.5) Titanium can be produced from TiO_2 from the following two reactions

$TiO_2 + C + 2Cl_2 \rightarrow TiCl_4 + CO_2$ The first reaction has a percentage yield of 90%

$TiCl_4 + 4Na \rightarrow 4NaCl + Ti$ The second reaction has a percentage yield of 95%

Calculate the actual mass of titanium that can be produced from 1.00kg of TiO_2 taking into account the percentage yields.

% Atom Economy

$$\text{percentage atom economy} = \frac{\textbf{Mass of useful products}}{\textbf{Mass of all reactants}} \times 100$$

Do take into account balancing numbers when working out % atom economy.

Example 8 : Calculate the % atom economy for the following reaction where iron is the desired product assuming the reaction goes to completion.

$Fe_2O_3 + 3CO \rightarrow 2Fe + 3\ CO_2$

$$\%\text{ atom economy} = \frac{(2 \times 55.8)}{(2 \times 55.8 + 3\times16) + 3 \times (12+16)} \times 100$$

$=45.8\%$

Sustainable chemistry requires chemists to design processes with high atom economy that minimise production of waste products.

Reactions where there is only one product where all atoms are used making product are ideal and have 100% atom economy.
e.g. $CH_2{=}CH_2 + H_2 \rightarrow CH_3CH_3$

If a process does have a side, waste product the economics of the process can be improved by selling the bi-product for other uses.

8.1) Calculate the atom economy to make urea from the following equation

$2\ NH_3 + CO_2 \rightarrow (NH_2)_2CO + H_2O$

Urea

8.2) Calculate the atom economy to make epoxyethane from the following equation

$C_2H_4 + Cl_2 + Ca(OH)_2 \rightarrow C_2H_4O + CaCl_2 + H_2O$

Epoxyethane

8.3) Calculate the atom economy to make hydrogen from the reaction of zinc with HCl.

$Zn + 2\ HCl \rightarrow ZnCl_2 + H_2$

8.4) Calculate the % atom economy for the formation of CH_2Cl_2 in this reaction

$CH_4 + 2Cl_2 \rightarrow CH_2Cl_2 + 2\ HCl$

8.5) Calculate the % atom economy for the formation of $C_6H_{12}Cl_2$ in this reaction

$C_6H_{14} + 2\ Cl_2 \rightarrow C_6H_{12}Cl_2 + 2\ HCl$

8.6) Calculate the % atom economy for the formation of Br_2 in this reaction

$2\ KBr + Cl_2 \rightarrow Br_2 + 2\ KCl$

8.7) Calculate the % atom economy for the formation of NH_3 in this reaction

$(NH_4)_2SO_4 + 2\ NaOH \rightarrow 2NH_3 + Na_2SO_4 + 2\ H_2O$

8.8) Calculate the % atom economy to make sodium carbonate from this reaction

$CaCO_3 + 2\ NaCl \rightarrow CaCl_2 + Na_2CO_3$

8.9) Calculate the % atom economy for the formation of TiO_2 in this reaction

$TiCl_4(l) + 2\ H_2O(l) \rightarrow TiO_2(s) + 4\ HCl(aq)$

Answers

1.1) 4.21g
1.2) 1.39g
1.3) 1579g
1.4) 239g
1.5) 0.418g

2.1) 31.5g
2.2) 60.6g
2.3) 61.0g
2.4) 145g
2.5) 18.4g

3.1) 0.500g
3.2) 51.8g
3.3) 27.4cm^3
3.4) 6.25g
3.5) 2.38g
3.6) 6.86g 5.14dm^3
3.7) 7.78g
3.8) 1.24 mol dm^{-3}

4.1) 118
4.2) *M*r =124 x=1
4.3) 235
4.4) 18%
4.5) 138 M=39, K
4.6) 12.2 mol dm^{-3}

5.1) 0.906
5.2) 544
5.3) 72.6, Ge
5.4) 89.8%
5.5) 5.13 x10^{-6} m^3 and % (if using ideal gas equation)

6.1) 68.6%
6.2) 2.65 x10^{-4}
6.3) 72.6%
6.4) 63.3%
6.5) 57.6%
6.6) *M*r 184.3 , *A*r 24.2 , Mg

7.1) 89%
7.2) 88%
7.3) 7.02g
7.4) 6.01g
7.5) 513g

8.1) 76.9%
8.2) 25.4%
8.3) 1.44%
8.4) 53.8%
8.5) 68.0%
8.6) 51.7%
8.7) 16%
8.8) 48.8%
8.9) 35.4%