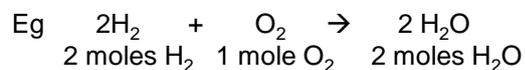


## 1.24 Calculations and Chemical Reactions

### 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.



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



The balancing (stoichiometric) numbers are the mole ratios  
e.g. **1** mol of  $\text{N}_2$  reacts with **3** mol of  $\text{H}_2$  to produce **2** mol of  $\text{NH}_3$

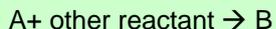
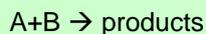
Most calculations will only involve two substances from the reaction and it is only necessary to identify the mole reacting ratio between those two substances.

So if a reaction involved 0.5 mol of  $\text{N}_2$  we can say it would react with 1.5 mol of  $\text{H}_2$  using the 1  $\text{N}_2$  :3  $\text{H}_2$  ratio

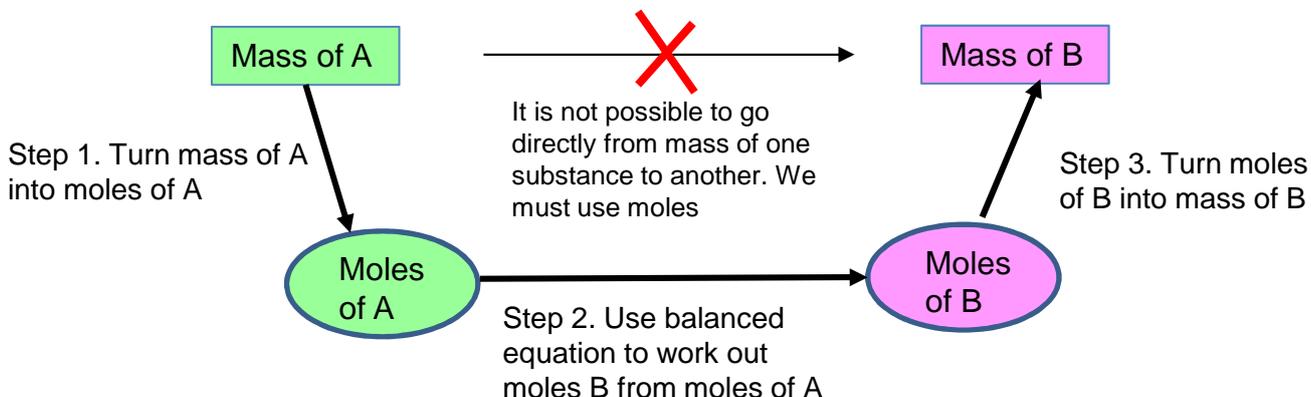
Or if 0.4 moles of  $\text{NH}_3$  was produced we would need 0.6 mol of  $\text{H}_2$  using the 2  $\text{NH}_3$  :3  $\text{H}_2$  ratio

## 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 can be any two reactants or products

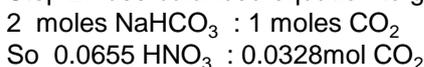


**Example 1** What mass of Carbon dioxide would be produced from heating 5.5 g of sodium hydrogencarbonate?  
 $2\text{NaHCO}_3 \rightarrow \text{Na}_2\text{CO}_3 + \text{CO}_2 + \text{H}_2\text{O}$

Step 1: work out amount, in mol, of sodium hydrogencarbonate

$$\begin{aligned} \text{amount} &= \text{mass} / \text{Mr} \\ &= 5.5 / 84.0 \\ &= 0.0655 \text{ mol} \end{aligned}$$

Step 2: use balanced equation to give amount in mol of  $\text{CO}_2$



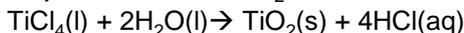
Step 3: work out mass of  $\text{CO}_2$

$$\begin{aligned} \text{Mass} &= \text{amount} \times \text{Mr} \\ &= 0.0328 \times 44.0 \\ &= 1.44 \text{ g} \end{aligned}$$

Remember stoichiometric balancing numbers are not used to calculate Mr. The Mr of  $\text{NaHCO}_3$  is always 84.0 whatever the balancing number in front of it

## Reacting Mass Questions

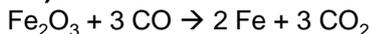
1.1) What mass of  $\text{TiO}_2$  can be made from reacting 10.0g of  $\text{TiCl}_4$  with water?



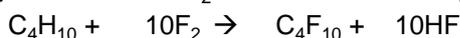
1.2) What mass of calcium chloride can be formed when 0.500 g of calcium reacts with hydrochloric acid?



1.3) What mass of carbon monoxide is needed to reduce 3.00 kg of iron oxide to iron?



1.4) What mass of  $\text{F}_2$  would be needed to produce 150 g of  $\text{C}_4\text{F}_{10}$ ?



1.5) What mass of NO would be produced from 0.500 g of CuS reacting with concentrated nitric acid?



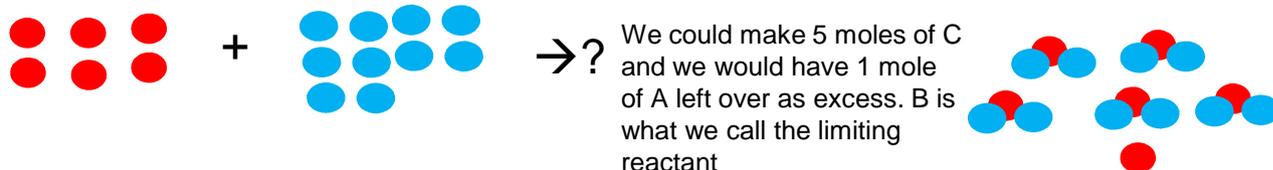
## Limiting and excess reactants

If a question gives masses of two or 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 ratio of 1A:2B

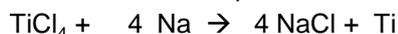


If we had 6 moles of A and 10 of B, which is in excess and how much C would be produced?



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  $\text{TiCl}_4$  with 80 g of sodium.



Step 1: work out amount, in mol,  $\text{TiCl}_4$

$$\begin{aligned} \text{amount} &= \text{mass} / \text{Mr} \\ &= 100 / 189.9 \\ &= 0.527 \text{ mol} \end{aligned}$$

Step 1: work out amount, in mol, Na

$$\begin{aligned} \text{amount} &= \text{mass} / \text{Mr} \\ &= 80 / 23.0 \\ &= 3.48 \text{ mol} \end{aligned}$$

Step 2 use balanced equation to work out which reactant is in excess

Using 1 $\text{TiCl}_4$ :4 Na ratio we can see that 0.527 mol of  $\text{TiCl}_4$  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  $\text{TiCl}_4$

Step 3: use balanced equation to work out amount in mol of Ti formed

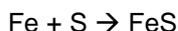
1 mol  $\text{TiCl}_4$ : 1 mole Ti

So 0.527 mol  $\text{TiCl}_4$  produces 0.527 mole Ti

Step 4: work out mass of Ti formed

$$\begin{aligned} \text{Mass} &= \text{amount} \times \text{Mr} \\ &= 0.527 \times 47.9 \\ &= 25.24 \text{ g} \end{aligned}$$

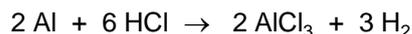
**2.1)** Calculate the maximum mass of iron sulphide that can be produced from 20.0 g of iron and 30.0g of sulphur



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



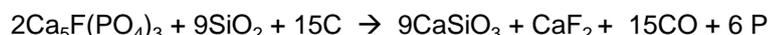
**2.3)** Calculate the maximum mass of aluminium chloride that can be produced from 25.0 g of aluminium and 50.0 g of HCl



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



**2.5)** Calculate the maximum mass of phosphorus that can be produced from reacting 100g of  $\text{Ca}_5\text{F}(\text{PO}_4)_3$ , 100g of  $\text{SiO}_2$  and 100g of Carbon



## 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

$$\text{Gas Volume (dm}^3\text{)} = \text{amount} \times 24$$

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<sup>-3</sup> or M  
Unit of Volume: dm<sup>3</sup>

### 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

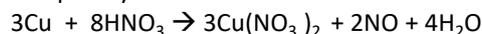
#### Step 2:

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:** What mass of Copper would react completely with 150 cm<sup>3</sup> of 1.6M nitric acid?

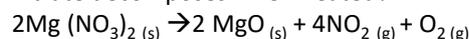


Step 1: work out moles of nitric acid  
amount = conc x vol  
= 1.6 x 0.15  
= 0.24 mol

Step 2: use balanced equation to give moles of Cu  
8 moles HNO<sub>3</sub> : 3 moles Cu  
So 0.24 HNO<sub>3</sub> : 0.09 (0.24 x <sup>3</sup>/<sub>8</sub>) mol Cu

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

**Example 4:** What is the total volume of gas produced in dm<sup>3</sup> at 333K and 100kPa when 0.651 g of magnesium nitrate decomposes when heated?



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

Step 2: use balanced equation to give moles of gas produced  
2 moles Mg(NO<sub>3</sub>)<sub>2</sub> : 4NO<sub>2(g)</sub> + O<sub>2(g)</sub> ie 5moles of gas  
So 0.00439 Mg(NO<sub>3</sub>)<sub>2</sub> : 0.01098 (0.00439 x <sup>5</sup>/<sub>2</sub>) moles gas

Step 3: work out volume of gas

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

## Questions involving masses, solutions and gases

**3.1)** Hydrogen can be made by the reaction of hydrochloric acid with magnesium according to the equation  $2\text{HCl} + \text{Mg} \rightarrow \text{MgCl}_2 + \text{H}_2$

What mass of hydrogen is formed when  $200\text{cm}^3$  of hydrochloric acid of concentration  $2.50\text{ mol dm}^{-3}$  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.



An excess of lead(II) oxide reacted with  $250\text{cm}^3$  of  $1.25\text{ mol dm}^{-3}$  nitric acid. Calculate the maximum mass of lead(II) nitrate which could have been obtained.

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

**3.4)** A volume of  $150\text{cm}^3$  of  $1.75\text{ mol dm}^{-3}$  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.  $3\text{Cu} + 8\text{HNO}_3 \rightarrow 3\text{Cu}(\text{NO}_3)_2 + 2\text{NO} + 4\text{H}_2\text{O}$

**3.5)** A sample of Sodium hydrogencarbonate was heated until completely decomposed. The  $\text{CO}_2$  formed in the reaction occupied a volume of  $352\text{ cm}^3$  at  $1.00 \times 10^5\text{ Pa}$  and  $298\text{ K}$ . Calculate the mass of the  $\text{NaHCO}_3$  that has decomposed.



**3.6)** Oxygen may be prepared by the decomposition of hydrogen peroxide,  $\text{H}_2\text{O}_2$ , as shown in the equation.  $2\text{H}_2\text{O}_2(\text{aq}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g})$

A  $160\text{ cm}^3$  sample of  $2.68\text{ mol dm}^{-3}$  aqueous hydrogen peroxide was decomposed completely. Calculate mass and volume of oxygen gas produced at room temperature and pressure.

**3.7)** Phosphine,  $\text{PH}_3$ , and oxygen can react to form phosphoric acid,  $\text{H}_3\text{PO}_4$ , as shown in the equation below.  $\text{PH}_3 + 2\text{O}_2 \rightarrow \text{H}_3\text{PO}_4$

An excess of oxygen was mixed with  $2.70\text{ g}$  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.



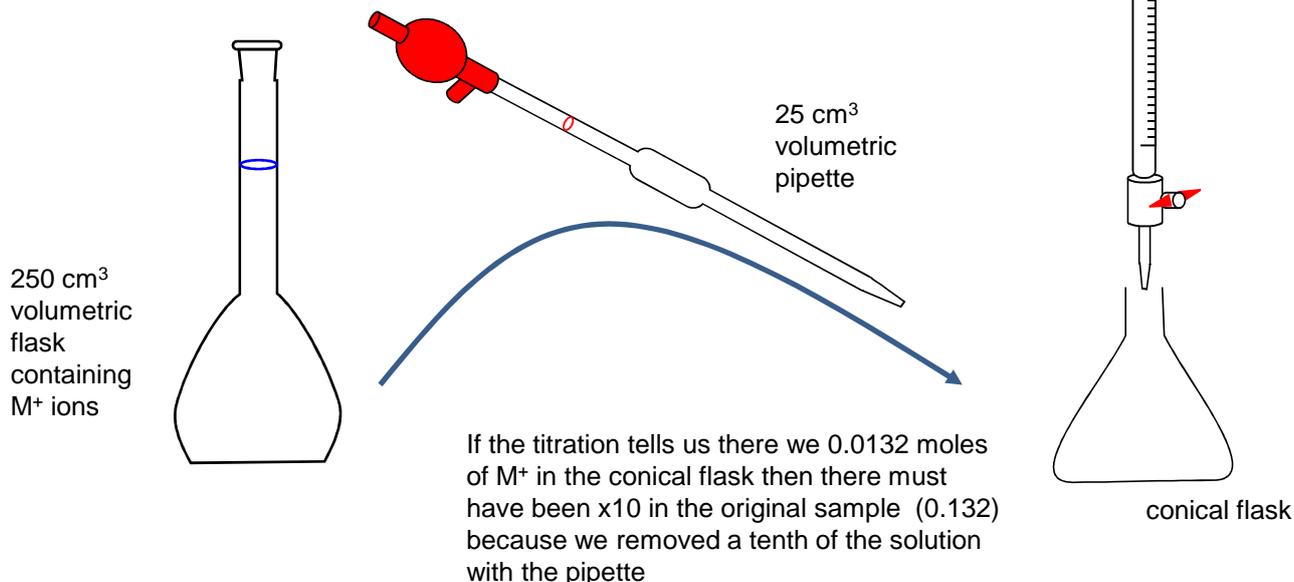
A  $3.24\text{ g}$  sample of ammonium sulfate reacted completely with  $39.70\text{cm}^3$  of a sodium hydroxide solution. Calculate the concentration, in  $\text{mol dm}^{-3}$ , of the sodium hydroxide solution used.

## Questions involving samples being taken

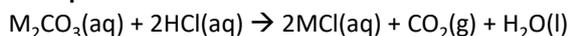
There are many variations on these calculations. It is not possible to learn an exact method for every type of calculation you could ever meet. You need to be able to go back to the chemistry and picture what is happening. Sometimes it is actually a good idea to draw out what is happening. Let's look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



**Example 5.** An unknown metal carbonate reacts with hydrochloric acid according to the following equation.



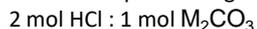
A 3.96 g sample of M<sub>2</sub>CO<sub>3</sub> was dissolved in distilled water to make 250 cm<sup>3</sup> of solution. A 25.0 cm<sup>3</sup> portion of this solution required 32.8 cm<sup>3</sup> of 0.175 mol dm<sup>-3</sup> hydrochloric acid for complete reaction. Calculate the Mr of M<sub>2</sub>CO<sub>3</sub> and identify the metal M

1. Calculate the number of moles of HCl used

$$\begin{aligned}\text{amount} &= \text{conc} \times \text{vol} \\ &= 0.175 \times 0.0328 \\ &= 0.00574 \text{ mol}\end{aligned}$$

2. Work out number of moles of M<sub>2</sub>CO<sub>3</sub> in 25.0 cm<sup>3</sup> put in conical flask

use balanced equation to give moles of M<sub>2</sub>CO<sub>3</sub>



So 0.00574 NaOH : 0.00287 moles M<sub>2</sub>CO<sub>3</sub>

3. Calculate the number of moles M<sub>2</sub>CO<sub>3</sub> acid in original 250 cm<sup>3</sup> of solution

$$\begin{aligned}\text{Moles in } 250\text{cm}^3 &= 0.00287 \times 10 \\ &= 0.0287\end{aligned}$$

4. work out the Mr of M<sub>2</sub>CO<sub>3</sub>

$$\begin{aligned}\text{Mr} &= \text{mass} / \text{amount} \\ &= 3.96 / 0.0287 = 138.0\end{aligned}$$

5. Work out Ar of M =  $\frac{138-12-16 \times 3}{2}$

$$\text{Ar of M} = 39$$

M = potassium

## Questions involving samples being taken

**4.1)** An acid,  $H_2A$ , reacts with sodium hydroxide as shown in the equation below.



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  $Na_2CO_3 \cdot xH_2O$ . A 2.98 g sample of one of these hydrates was dissolved in water and the solution made up to 250  $cm^3$ . 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.



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  $M_r$  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 500  $cm^3$  in a volumetric flask. A 25.0  $cm^3$  portion of this solution was then reacted with 26.8  $cm^3$  of 0.20  $mol\ dm^{-3}$  sulphuric acid. What is the percentage by mass of ammonia in the cleaning solution  $2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$

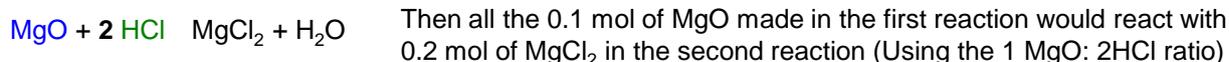
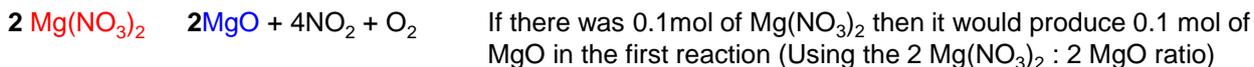
**4.5)** 1.70 g of a metal carbonate,  $M_2CO_3$ , was dissolved in water and the solution was made up to 250  $cm^3$  in a volumetric flask. 25.0  $cm^3$  of this solution was then reacted with 24.6  $cm^3$  of 0.100  $mol\ dm^{-3}$  hydrochloric acid. Calculate the relative formula mass of  $M_2CO_3$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

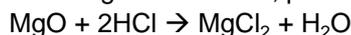


*Remember the balancing numbers give the mole ratios for that equation. Don't try to link balancing numbers in one reaction to the balancing numbers in the second*

**5.1)** A 2.23g sample of magnesium nitrate was fully decomposed.



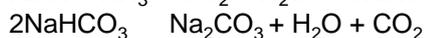
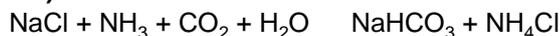
The magnesium oxide, produced was reacted with hydrochloric acid.



This sample of magnesium oxide required 33.2cm<sup>3</sup> of hydrochloric acid for complete reaction.

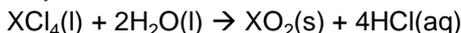
Calculate the concentration, in mol dm<sup>-3</sup>, of the hydrochloric acid.

**5.2)** Sodium carbonate is manufactured in a two-stage process as shown by the equations below.



Calculate the maximum mass of sodium carbonate which could be obtained from 600 g of sodium chloride.

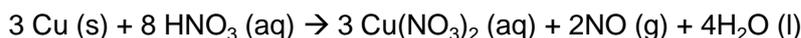
**5.3)** The chloride of an element **X** reacts with water according to the following equation.



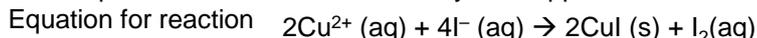
A 1.436 g sample of  $\text{XCl}_4$  was added to water. The solid  $\text{XO}_2$  was removed by filtration and the resulting solution was made up to 250 cm<sup>3</sup> in a volumetric flask. A 25.0 cm<sup>3</sup> portion of this solution was titrated against a 0.120 mol dm<sup>-3</sup> solution of sodium hydroxide, of which 22.3 cm<sup>3</sup> were required to reach the end point.  $\text{NaOH} + \text{HCl} \rightarrow \text{NaCl} + \text{H}_2\text{O}$

Calculate the relative molecular mass,  $M_r$ , of  $\text{XCl}_4$  and then deduce the relative atomic mass,  $A_r$ , of element **X** and its identity.

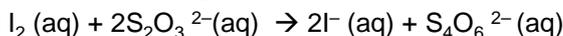
**5.4)** A old bronze coin of mass 2.15g containing copper and tin was dissolved in concentrated nitric acid and the NO gas escaped through boiling. The equation below shows the reaction of the copper with the acid



The solution was diluted with water to make up to 250cm<sup>3</sup>. 25cm<sup>3</sup> portions were neutralised and added to excess potassium iodide solution. Only the copper ions reacted with the iodide ions to produce iodine.



The liberated iodine was then titrated with sodium thiosulphate. The iodine required 30.40cm<sup>3</sup> of 0.100 mol dm<sup>-3</sup> sodium thiosulphate ( $\text{Na}_2\text{S}_2\text{O}_3$ ) to react.



What is 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  $\text{O}_3 + 2 \text{I}^{-} + 2 \text{H}^{+} \rightarrow \text{O}_2 + \text{H}_2\text{O} + \text{I}_2$

The amount of iodine formed can be determined by titration with a solution of sodium thiosulfate of known concentration in the following reaction  $\text{I}_2 + 2 \text{S}_2\text{O}_3^{2-} \rightarrow 2 \text{I}^{-} + \text{S}_4\text{O}_6^{2-}$

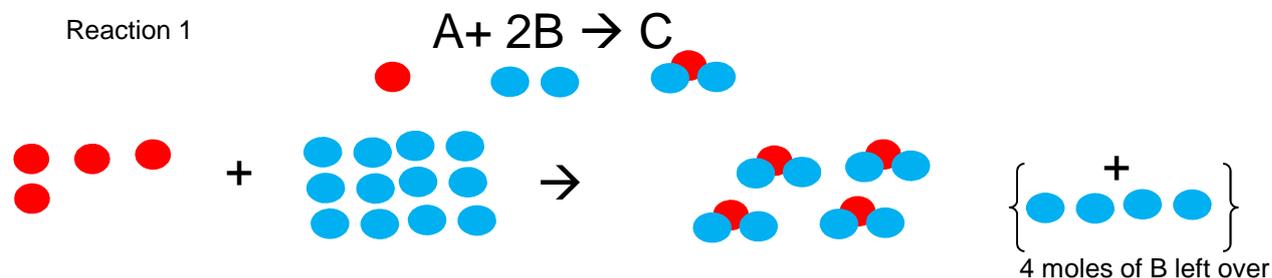
In an experiment to determine the amount of ozone in air, 100 m<sup>3</sup> of air was bubbled through 100 cm<sup>3</sup> of a solution containing an excess of acidified potassium iodide. The resulting solution was titrated against a solution of sodium thiosulfate of concentration 0.0167 mol dm<sup>-3</sup>. The volume of sodium thiosulfate solution required for the complete reaction was 24.80 cm<sup>3</sup>.

Calculate the amount in moles of Ozone in the 100m<sup>3</sup> sample and calculate the volume of Ozone in m<sup>3</sup>. (assuming the volume is measured at room temperature and pressure). What percentage by volume of air is ozone?

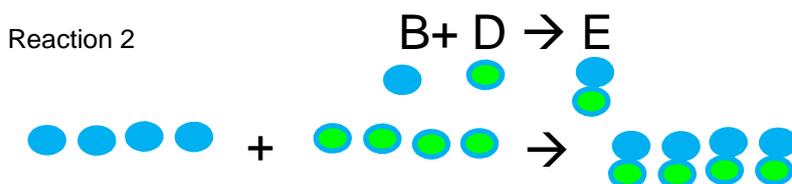
The second type of calculation involving two different reactions occurs when the first reaction leaves an excess reactant. The second reaction then involves the reaction of the excess reactant.

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?



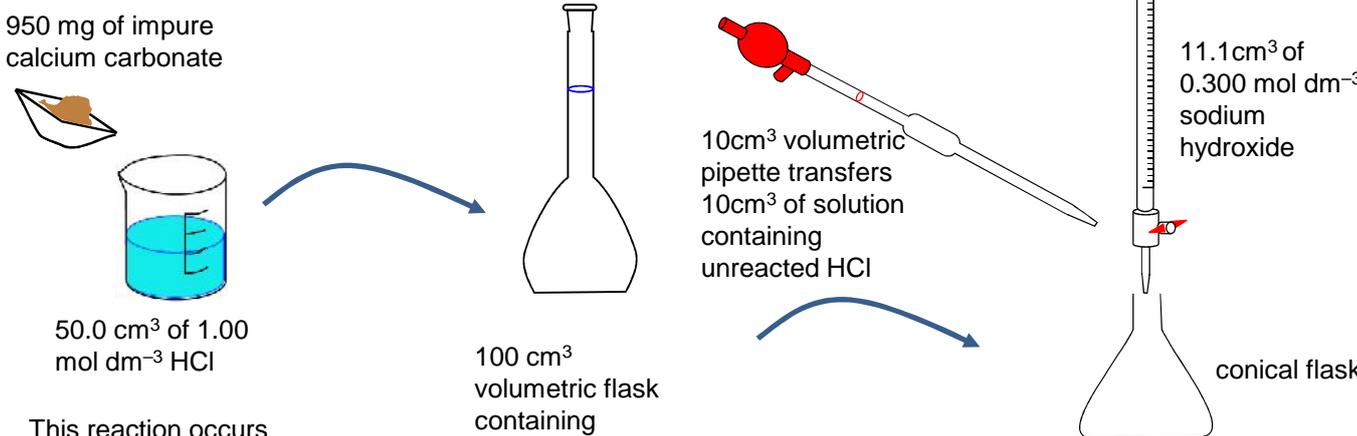
The 4 moles of B left over would react with 4 moles of D



Now try this problem. If 17 moles of B reacted with a 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<sup>3</sup> of 1.00 mol dm<sup>-3</sup> 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<sup>3</sup> with distilled water. 10.0 cm<sup>3</sup> of this solution was titrated with 11.1 cm<sup>3</sup> of 0.300 mol dm<sup>-3</sup> sodium hydroxide solution. What is the percentage of CaCO<sub>3</sub> by mass in the tablet



950 mg of impure calcium carbonate

50.0 cm<sup>3</sup> of 1.00 mol dm<sup>-3</sup> HCl

100 cm<sup>3</sup> volumetric flask containing unreacted HCl made up to 100 cm<sup>3</sup> distilled water.

10 cm<sup>3</sup> volumetric pipette transfers 10 cm<sup>3</sup> of solution containing unreacted HCl

11.1 cm<sup>3</sup> of 0.300 mol dm<sup>-3</sup> sodium hydroxide

conical flask

This reaction occurs  
 $\text{CaCO}_3(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{CaCl}_2(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$   
 All the CaCO<sub>3</sub> is reacted  
 some HCl is left over

This reaction occurs  
 $\text{NaOH} + \text{HCl}(\text{aq}) \rightarrow \text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l})$   
 The NaOH reacts with left over HCl in 10 cm<sup>3</sup> solution

The calculation works backwards using the titration results first.

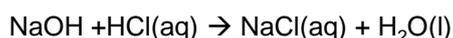
950 mg of impure calcium carbonate tablet was crushed. 50.0 cm<sup>3</sup> of 1.00 mol dm<sup>-3</sup> hydrochloric acid, an excess, was then added and the mixture was transferred to a volumetric flask. The volume was made up to exactly 100 cm<sup>3</sup> with distilled water. 10.0 cm<sup>3</sup> of this solution was titrated with 11.1 cm<sup>3</sup> of 0.300 mol dm<sup>-3</sup> sodium hydroxide solution.

What is the percentage of CaCO<sub>3</sub> by mass in the tablet?

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

$$\begin{aligned}\text{amount} &= \text{conc} \times \text{vol} \\ &= 0.30 \times 0.0111 \\ &= 0.00333 \text{ mol}\end{aligned}$$

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



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<sup>3</sup> pipette

3. Calculate the amount in moles of hydrochloric acid left in 100 cm<sup>3</sup> of solution.

$$\begin{aligned}\text{Moles in } 100\text{cm}^3 &= 0.00333 \times 10 \\ &= 0.0333\text{mol}\end{aligned}$$

The 10cm<sup>3</sup> pipetted sample came from the 100cm<sup>3</sup> volumetric flask so to work out the amount of moles in the flask we multiply by 10

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

In original HCl 50.0 cm<sup>3</sup> of 1.00 mol dm<sup>-3</sup> there is 0.05mol

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<sub>3</sub> 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<sub>3</sub> that reacted with the HCl



2 mol HCl : 1 mol CaCO<sub>3</sub>

So 0.0167 HCl : 0.00835 moles CaCO<sub>3</sub>

6. work out the mass of CaCO<sub>3</sub> in original tablet

$$\begin{aligned}\text{mass} &= \text{amount} \times \text{Mr} \\ &= 0.00835 \times 100.1 = 0.836 \text{ g}\end{aligned}$$

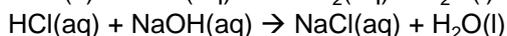
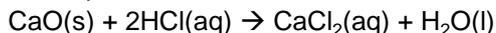
7. Calculate percentage of CaCO<sub>3</sub> by mass in the tablet = 0.836/0.950 x100 = 88.0 %

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

## Back Titration questions

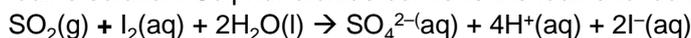
**6.1)** A 0.132 g of an impure sample of quicklime was dissolved in 50.0 cm<sup>3</sup> of hydrochloric acid, concentration 0.100 mol dm<sup>-3</sup>. The excess hydrochloric acid was titrated with sodium hydroxide solution, concentration 0.100 mol dm<sup>-3</sup>, and 17.7 cm<sup>3</sup> was needed to just neutralize the acid.

The equations for the reactions involved are shown below.



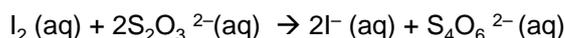
Calculate the percentage purity of the Calcium oxide.

**6.2)** The amount of sulphur dioxide in the air can be measured by bubbling a known volume of air through iodine solution. Sulphur dioxide converts the iodine to iodide ions according to the following equation.



In an experiment, 75 m<sup>3</sup> of air were passed through 50 cm<sup>3</sup> of iodine, of concentration 0.0200 mol dm<sup>-3</sup>.

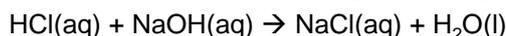
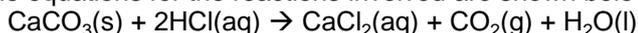
The remaining iodine was titrated with sodium thiosulphate solution and reacted with 14.70 cm<sup>3</sup> of sodium thiosulphate, concentration 0.100 mol dm<sup>-3</sup>.



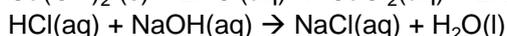
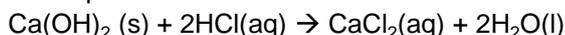
Calculate the moles of sulphur dioxide that were in the original 75m<sup>3</sup> sample.

**6.3)** 9.8 g of a indigestion remedy containing calcium carbonate was reacted with 100 cm<sup>3</sup> of 2.00 mol dm<sup>-3</sup> hydrochloric acid. (Only the calcium carbonate in the remedy reacts). The resulting solution was made up to 250 cm<sup>3</sup> with water in a volumetric flask. A 25.0 cm<sup>3</sup> portion of this solution required 28.9 cm<sup>3</sup> of 0.200 mol dm<sup>-3</sup> sodium hydroxide for neutralisation. Find the percentage by mass of the calcium carbonate in the indigestion remedy.

The equations for the reactions involved are shown below.



**6.4)** 1.13 g of an impure sample of calcium hydroxide was dissolved in 50.0 cm<sup>3</sup> of hydrochloric acid, concentration 1.00 mol dm<sup>-3</sup>. The resulting solution was made up to 250 cm<sup>3</sup> with water in a volumetric flask. A 25.0 cm<sup>3</sup> portion of this solution required 30.7 cm<sup>3</sup> of 0.100 mol dm<sup>-3</sup> sodium hydroxide for neutralisation. The equations for the reactions involved are shown below.

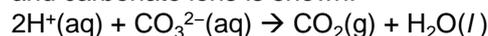


Calculate the percentage purity of the Calcium hydroxide.

**6.5)** 1.50g of Bordeaux mixture containing a mixture of calcium hydroxide (Ca(OH)<sub>2</sub>) and copper(II) sulfate-5-water (CuSO<sub>4</sub>·5H<sub>2</sub>O) was added to 25.0 cm<sup>3</sup> of hydrochloric acid, concentration 2.00 mol dm<sup>-3</sup>. The calcium hydroxide in the mixture will neutralise some of the acid. The resulting solution was made up to 250 cm<sup>3</sup> with water in a volumetric flask. A 25.0 cm<sup>3</sup> portion of this solution required 26.7 cm<sup>3</sup> of 0.100 mol dm<sup>-3</sup> 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<sub>3</sub>)<sub>2</sub> 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.



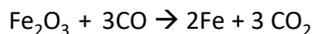
A 6.00 g sample of dolomite is dissolved in 35.0 cm<sup>3</sup> of 5.00 mol dm<sup>-3</sup> hydrochloric acid, which is an excess. The resulting solution is made up to 100 cm<sup>3</sup> in a volumetric flask, using distilled water. 10.0 cm<sup>3</sup> portions of this solution are titrated against sodium hydroxide. 22.40 cm<sup>3</sup> of 0.200 mol dm<sup>-3</sup> NaOH is required for neutralisation. Calculate the relative formula mass of CaX(CO<sub>3</sub>)<sub>2</sub> 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<sub>2</sub>O<sub>3</sub> was reacted and it produced 10g of Fe. What is the percentage yield?



First calculate maximum mass of Fe that could be produced

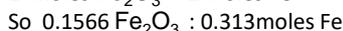
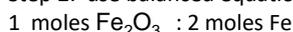
Step 1: work out amount in mol of Iron oxide

$$\text{amount} = \text{mass} / \text{Mr}$$

$$= 25 / 159.6$$

$$= 0.1566 \text{ mol}$$

Step 2: use balanced equation to give moles of Fe



Step 3: work out mass of Fe

$$\text{Mass} = \text{amount} \times \text{Mr}$$

$$= 0.313 \times 55.8$$

$$= 17.48\text{g}$$

$$\% \text{ yield} = (\text{actual yield} / \text{theoretical yield}) \times 100$$

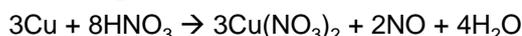
$$= (10 / 17.48) \times 100$$

$$= 57.2\%$$

**7.1)** 10.0 g of CaCO<sub>3</sub> was reacted with H<sub>2</sub>SO<sub>3</sub>. The reaction was incomplete and only 10.7g of CaSO<sub>3</sub> was formed. Calculate the percentage yield of the reaction



**7.2)** 5.70g of Copper metal was reacted with HNO<sub>3</sub>. The reaction was incomplete and only 14.80g of Cu(NO<sub>3</sub>)<sub>2</sub> was formed. Calculate the percentage yield of the reaction.



**7.3)** 5.78 g of magnesium carbonate were added to an excess of sulfuric acid. The following reaction occurred.

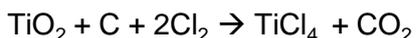


Calculate the actual mass of MgSO<sub>4</sub> produced in this reaction assuming a 85% yield.

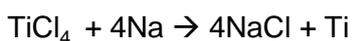
**7.4)** The reaction from ethanoic acid (CH<sub>3</sub>COOH) has a percentage yield of 82%. What is the minimum mass of butane that would be needed to actually produce 10.2g of CH<sub>3</sub>COOH



**7.5)** Titanium can be produced from TiO<sub>2</sub> from the following two reactions



The first reaction has a percentage yield of 90%



The second reaction has a percentage yield of 95%

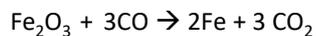
Calculate the actual mass of Titanium that can be produced from 1.00kg of TiO<sub>2</sub> taking into account the percentage yields.

## % Atom Economy

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

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

**Example 8** : What is the % atom economy for the following reaction where Fe is the desired product assuming the reaction goes to completion?



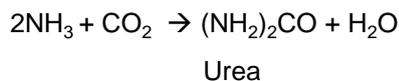
$$\begin{aligned} \text{\% atom economy} &= \frac{(2 \times 55.8)}{(2 \times 55.8 + 3 \times 16) + 3 \times (12 + 16)} \times 100 \\ &= 45.8\% \end{aligned}$$

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

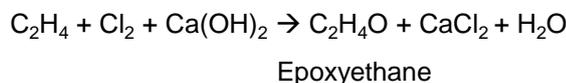
Reactions where there is only one product where all atoms are used making product are ideal and have 100% atom economy.  
e.g.  $\text{CH}_2=\text{CH}_2 + \text{H}_2 \rightarrow \text{CH}_3\text{CH}_3$

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

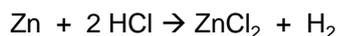
**8.1)** Calculate the atom economy to make urea from the following equation



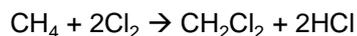
**8.2)** Calculate the atom economy to make epoxyethane from the following equation



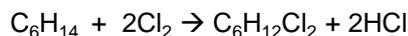
**8.3)** Calculate the atom economy to make hydrogen from the reaction of zinc with HCl.



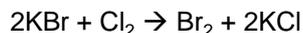
**8.4)** Calculate the % atom economy for the formation of  $\text{CH}_2\text{Cl}_2$  in this reaction



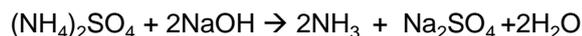
**8.5)** Calculate the % atom economy for the formation of  $\text{C}_6\text{H}_{12}\text{Cl}_2$  in this reaction



**8.6)** Calculate the % atom economy for the formation of  $\text{Br}_2$  in this reaction



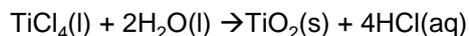
**8.7)** Calculate the % atom economy for the formation of  $\text{NH}_3$  in this reaction



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



**8.9)** Calculate the % atom economy for the formation of  $\text{TiO}_2$  in this reaction



## Answers

- |             |            |
|-------------|------------|
| 1.1) 4.21g  | 2.1) 31.5g |
| 1.2) 1.39g  | 2.2) 60.6g |
| 1.3) 1579g  | 2.3) 61.0g |
| 1.4) 239g   | 2.4) 145g  |
| 1.5) 0.418g | 2.5) 18.4g |

- |                                |                                |
|--------------------------------|--------------------------------|
| 3.1) 0.500g                    | 4.1) 118                       |
| 3.2) 51.8g                     | 4.2) $M_r = 124$ $x=1$         |
| 3.3) 27.4cm <sup>3</sup>       | 4.3) 235                       |
| 3.4) 6.25g                     | 4.4) 18%                       |
| 3.5) 2.38g                     | 4.5) 138 $M=39$ , K            |
| 3.6) 6.86g 5.14dm <sup>3</sup> | 4.6) 12.2 mol dm <sup>-3</sup> |
| 3.7) 7.78g                     |                                |
| 3.8) 1.24 mol dm <sup>-3</sup> |                                |

- 5.1) 0.906  
5.2) 544  
5.3) 72.6, Ge  
5.4) 89.8%  
5.5) 5.13 x10<sup>-6</sup> m<sup>3</sup> and % (if using ideal gas equation)

- 6.1) 68.6%  
6.2) 2.65 x10<sup>-4</sup>  
6.3) 72.6%  
6.4) 63.3%  
6.5) 57.6%  
6.6)  $M_r$ 184.3 , Ar 24.2 , Mg

- |            |            |
|------------|------------|
| 7.1) 89%   | 8.1) 76.9% |
| 7.2) 88%   | 8.2) 25.4% |
| 7.3) 7.02g | 8.3) 1.44% |
| 7.4) 6.01g | 8.4) 53.8% |
| 7.5) 513g  | 8.5) 68.0% |
|            | 8.6) 51.7% |
|            | 8.7) 16%   |
|            | 8.8) 48.8% |
|            | 8.9) 35.4% |