

Revision Checklist :4.3 Quantitative Chemistry

Conservation of Mass

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

This means that chemical reactions can be represented by symbol equations which are balanced in terms of the numbers of atoms of each element involved on both sides of the equation.

Balancing Equations

- know how to balance chemical equations
 $\text{CaCO}_3 + 2\text{HCl} \rightarrow \text{CaCl}_2 + \text{H}_2\text{O} + \text{CO}_2$ (The 2 is put in front of the HCl to balance the numbers of H's and Cl's on both sides)
 $2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$ (The 2 is put in front of the MgO to balance with the 2O's on the left and then a 2 needs to be put in front of the Mg to balance with the 2Mg's on the right.)
- Remember when balancing equations you cannot change the formulae

Relative Formula Mass

The relative formula mass (*Mr*) of a compound is the sum of the relative atomic masses (*Ar*) of the atoms in the numbers shown in the formula.

Be able to work out the relative formula mass (*Mr*) of a substance using data from the periodic table.
e.g. the *Mr* of $\text{CaCO}_3 = 40 + 12 + (16 \times 3) = 100$

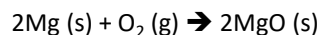
Balanced chemical equations

In a balanced chemical equation, the sum of the relative formula masses of the reactants in the quantities shown equals the sum of the relative formula masses of the products in the quantities shown

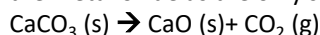
Mass changes when a reactant or product is a gas

Some reactions may appear to involve a change in mass but this can usually be explained because a reactant or product is a gas and its mass has not been taken into account

When a metal reacts with oxygen the mass of the oxide produced is greater than the mass of the metal.



In **thermal decompositions** of metal carbonates, carbon dioxide is produced and escapes into the atmosphere leaving the metal oxide as the only solid product.



Chemical measurements

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

The **range** of a set of measurements about the **mean** can be used as a measure of uncertainty.

Example: Calculate the mean and uncertainty of the following volumes in cm^3 : 20.10, 20.20, 20.00, 20.05, 20.25

$$\text{Mean} = (20.10 + 20.20 + 20.00 + 20.05 + 20.15) / 5 = 20.10 \text{ cm}^3$$

$$\text{Uncertainty} = \pm 0.10 \text{ cm}^3 \text{ (all readings are within } \pm 0.10 \text{ of mean)}$$

Moles

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

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

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

For example in one mole of carbon (C) the number of atoms is the same as the number of molecules in one mole of carbon dioxide (CO_2).

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.

be able to work out the number of moles of a given substance from its mass using the equation

$$\text{moles} = \text{mass} / \text{Mr} \text{ or rearranged to } \text{mass} = \text{Mr} \times \text{moles}$$

Avogadro's Constant

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.

Avogadro's Constant can be used for atoms, molecules and ions

1 mole of copper atoms will contain 6.02×10^{23} atoms

1 mole of carbon dioxide molecules will contain 6.02×10^{23} molecules

1 mole of sodium ions will contain 6.02×10^{23} ions

No of particles = number of moles X Avogadro's constant

Example 1 : How many atoms of Tin are there in a 6.00 g sample of Tin metal?

Step 1 calculate the number of moles

$$\begin{aligned}\text{moles} &= \text{mass}/A_r \\ &= 6/119 \\ &= 0.0504 \text{ mol}\end{aligned}$$

Step 2 use Avogadro's number to calculate no of atoms

$$\begin{aligned}\text{Number of atoms} &= \text{moles} \times 6.02 \times 10^{23} \\ &= 0.0504 \times 6.02 \times 10^{23} \\ &= 3.04 \times 10^{22}\end{aligned}$$

Example 2 calculate the mass of 1 atom of sodium

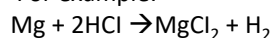
$$\begin{aligned}\text{Mass of 1 atom} &= \text{mass of 1 mole of sodium}(A_r)/\text{Avogadro's number} \\ &= 23/6.02 \times 10^{23} \\ &= 3.82 \times 10^{-23} \text{ g}\end{aligned}$$

Reacting Mass questions

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

Chemical equations can be interpreted in terms of moles.

For example:



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.

General method for reacting mass questions

step 1: work out the number of moles of the substance for which the mass has been given.

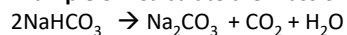
$$\text{Using } \text{Number of moles} = \frac{\text{mass}}{M_r}$$

step 2 : use the ratios of moles in the balanced equation to work out the moles of the other substance

Step 3: work out the mass of the second substance

$$\text{Using } \text{mass} = \text{moles} \times M_r$$

Example 3 : Calculate the mass of carbon dioxide produced from heating 5.5 g of sodium hydrogencarbonate.



Step 1: work out moles of sodium hydrogencarbonate

$$\begin{aligned}\text{Moles} &= \text{mass} / M_r \\ &= 5.5 / 84 \\ &= 0.0655 \text{ mol}\end{aligned}$$

Step 2: use balanced equation to give moles of CO_2

$$\begin{aligned}2 \text{ moles NaHCO}_3 &: 1 \text{ moles CO}_2 \\ \text{So } 0.0655 \text{ HNO}_3 &: 0.0328 \text{ moles CO}_2\end{aligned}$$

Step 3: work out mass of CO_2

$$\begin{aligned}\text{Mass} &= \text{moles} \times M_r \\ &= 0.0328 \times 44 \\ &= 1.44 \text{ g}\end{aligned}$$

Working out the balancing numbers from masses

The balancing numbers in a symbol equation can be calculated from the masses of reactants and products by converting the masses in grams to amounts in moles and converting the numbers of moles to simple whole number ratios.

Example 4. 8.01 g of copper reacts with sulfur to form 12.03 g of copper sulphide (CuS)

Calculate the moles of Cu, S and CuS and deduce the balanced equation.

Step 1: using conservation of mass work out mass of missing substance

mass of sulfur = mass of copper sulfide – mass of copper

mass of sulfur = 12.03-8.01
= 4.02g

Step 2: calculate moles of each chemical

Moles of Cu = mass / Ar
= 8.01 / 64
= 0.125 mol

Moles of S = mass / Ar
= 4.02 / 32
= 0.125 mol

Moles of CuS = mass / Mr
= 12.03 / 96
= 0.125 mol

Step 3: divide each moles in step 2 by the smallest number of moles to get a whole number ratio

Cu = 0.125/0.125
= 1

S = 0.125/0.125
= 1

CuS = 0.125/0.125
= 1

Step 4 write balanced equation

$1 \text{ Cu} + 1 \text{ S} \rightarrow 1 \text{ CuS}$ or $\text{Cu} + \text{S} \rightarrow \text{CuS}$

Limiting Reactant

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.

The number of moles of the limiting reactant will determine the number of moles of product formed.

Not all of the excess reactant will react.

General method for Limiting Reactant Questions

step 1: work out the number of moles of the substance for each reactant.

Using Number of moles = $\frac{\text{mass}}{\text{Mr}}$

step 2 : use the ratios of moles in the balanced equation to work out which reactant is the limiting reactant

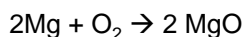
Step 3 : use the ratios of moles in the balanced equation to convert the moles of the limiting reactant to the moles of a product

Step 4: work out the mass of the product

Using mass = moles x Mr

Some questions may only ask you to calculate which reactant is in excess. In those questions only do the first two steps in the above method

Example 5: 5.0g of Magnesium are reacted with 6.0g of Oxygen to make magnesium oxide. What is the limiting reactant and calculate the mass of magnesium oxide that will be formed?



step 1: calculate the number of moles of the substance for each reactant.

$$\begin{aligned} \text{Work out moles of Mg} \\ \text{Moles} &= \text{mass} / A_r \\ &= 5/24 \\ &= 0.208\text{mol} \end{aligned}$$

$$\begin{aligned} \text{Work out moles of O}_2 \\ \text{Moles} &= \text{mass} / M_r \\ &= 6/32 \\ &= 0.188 \text{ mol} \end{aligned}$$

step2 : use the ratios of moles in the balanced equation to work out which reactant is the limiting reactant

Using ratio of 2Mg: 1 O₂ from balanced equation

0.208 moles of Mg should react with 0.104 of O₂

but we have 0.188 mol of O₂ so O₂ is in excess and **Mg is limiting reactant**

step 3 : use the ratios of moles in the balanced equation to convert the moles of the limiting reactant to the moles of a product

Ignore excess moles of O₂ and use moles of Mg to work out moles of MgO

There are 0.208 mol of Mg, so using ratio of 2Mg:2MgO from balanced equation there must be 0.208 mol of MgO

step 4: calculate the mass of the product

$$\begin{aligned} \text{Mass} &= \text{moles} \times M_r \text{ of MgO} \\ &= 0.208 \times 40 \\ &= 8.32\text{g} \end{aligned}$$

Concentration calculations

The concentration of a solution can be measured in g/dm³ or mol/dm³.

$$\text{Concentration (in mol/dm}^3\text{)} = \text{moles/volume (in dm}^3\text{)}$$

$$\text{Concentration (in g/dm}^3\text{)} = \text{mass (in g) /volume (in dm}^3\text{)}$$

The volume in the above equation must be in **dm³**. Volumes are often given in cm³.
To convert cm³ into dm³ divide by 1000

Example 6: Calculate the concentration of solution made by dissolving 5.00g of Na₂CO₃ in 250 cm³ water?

$$\begin{aligned} \text{moles} &= \text{mass} / M_r \\ &= 5.00 / (23 \times 2 + 12 + 16 \times 3) \\ &= 0.0472 \text{ mol} \\ \text{conc} &= \text{moles/Volume} \\ &= 0.0472 / 0.25 \\ &= 0.189 \text{ mol /dm}^3 \end{aligned}$$

Example 7: Calculate the mass of sodium chloride needed to make 100cm³ of 0.100 mol/dm³ NaCl solution?

$$\begin{aligned} \text{moles} &= \text{conc} \times \text{Volume} \\ &= 0.1 \times 0.1 \\ &= 0.01 \text{ mol} \\ \text{mass} &= \text{mol} \times M_r \\ &= 0.01 \times (23+35.5) \\ &= 0.585\text{g} \end{aligned}$$

To convert a concentration in **g/dm³** to **mol/dm³** divide by **Mr**

Example 8: A solution of HCl has a concentration of 1.825g/dm³. Calculate the concentration of the solution in mol/dm³

$$\begin{aligned} \text{Conc in mol/dm}^3 &= \text{conc in g/dm}^3 / M_r \\ &= 1.825 / 36.5 \\ &= 0.05 \text{ mol/dm}^3 \end{aligned}$$

Percentage Yield

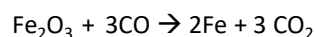
Even though no atoms are gained or lost in a chemical reaction, it is not always possible to obtain the calculated amount of a product because:

- 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 a product obtained is known as the yield. When compared with the maximum theoretical amount as a percentage, it is called the percentage yield.

$$\% \text{ Yield} = \frac{\text{Mass of product actually made}}{\text{maximum theoretical mass of product}} \times 100$$

Example 9: 25.0g of Fe_2O_3 was reacted and it produced 10.0g of Fe. Calculate the percentage yield?



First calculate maximum theoretical mass of Fe that could be produced

Step 1: work out moles of Iron oxide

$$\begin{aligned} \text{Moles} &= \text{mass} / M_r \\ &= 25.0 / 160 \\ &= 0.156 \text{ mol} \end{aligned}$$

Step 2: use balanced equation to give moles of Fe

$$\begin{aligned} 1 \text{ moles } \text{Fe}_2\text{O}_3 &: 2 \text{ moles Fe} \\ \text{So } 0.156 \text{ Fe}_2\text{O}_3 &: 0.313 \text{ moles Fe} \end{aligned}$$

Step 3: calculate maximum mass of Fe

$$\begin{aligned} \text{Mass} &= \text{moles} \times A_r \\ &= 0.313 \times 56 \\ &= 17.5\text{g} \end{aligned}$$

Step 4: calculate the percentage yield

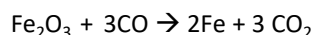
$$\begin{aligned} \% \text{ Yield} &= \frac{\text{Mass of product actually made}}{\text{maximum theoretical mass of product}} \times 100 \\ &= (10 / 17.5) \times 100 \\ &= 57.1\% \end{aligned}$$

Percentage atom economy

The atom economy (atom utilisation) is a measure of the amount of starting materials that end up as **useful products**. It is important for **sustainable development** and for economic reasons to use reactions with high atom economy.

$$\text{Percentage atom economy} = \frac{\text{Relative formula mass of desired product from equation}}{\text{Sum of relative formula masses of all reactants from equation}} \times 100$$

Example 10: Calculate the % atom economy for the following reaction where Fe is the desired product assuming the reaction goes to completion?



$$\begin{aligned} \% \text{ atom economy} &= \frac{(2 \times 56)}{(2 \times 56 + 3 \times 16) + 3 \times (12 + 16)} \times 100 \\ &= 45.9\% \end{aligned}$$

Required practical :Titrations

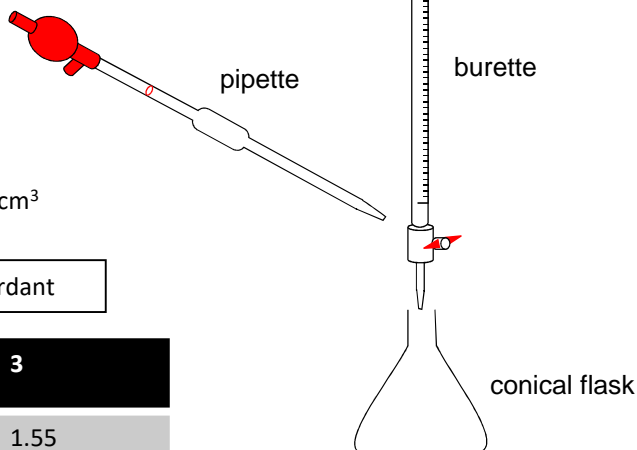
Chemistry only

The volumes of acid and alkali solutions that react with each other can be measured by titration using a suitable indicator.
If the volumes of two solutions that react completely are known and the concentration of one solution is known, the concentration of the other solution can be calculated.

A pipette measures one fixed volume accurately.
A burette measures variable volume

Know the basic method for doing a titration

- alkali in **burette**
- acid in **conical flask** measured out with a 25cm³ **pipette**
- few drops of indicator
- add alkali to acid until colour changes
- swirl conical flask
- add alkali dropwise towards the end
- note final burette reading
- repeat until two readings are within 0.1cm³



Results within 0.10cm³ of each other are called concordant

Titration number	1	2	3
Initial burette reading (cm ³)	0.50	2.50	1.55
Final burette reading (cm ³)	24.50	27.00	25.95
Titre (cm ³)	24.00	24.50	24.40

Working out average titre results
Only make an average of the concordant titre results

$$\text{Average titre} = (24.50 + 24.40) / 2 = 24.45$$

Titration calculations

General method

Step 1: calculate the number of moles of the substance for which the volume and concentration has been given.

Using **Number of moles = concentration x vol (in dm³)**

Step 2: use the balanced equation to work out the moles of the other substance

e.g. NaOH and HCl react on a 1:1 ratio (NaOH + HCl → NaCl + H₂O)

Step 3: calculate the concentration of the second substance

Using **concentration = moles / volume**

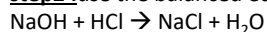
Example 11

If 25 cm³ of HCl is reacted with 22.4cm³ of 2 mol/dm³ NaOH, what would be the concentration of the HCl?

step 1: work out the number of moles of NaOH

$$\text{Number of moles} = \text{conc} \times \text{vol} = 2 \times 22.4 / 1000 = 0.0448 \text{ mol}$$

step 2: use the balanced equation to work out the moles of HCl



1 mole NaOH reacts with 1 mole HCl **1:1 ratio**

So 0.0448 moles NaOH reacts with 0.0448 moles HCl

Step 3: work out the conc of HCl

$$\begin{aligned} \text{concentration} &= \text{moles} / \text{volume} \\ &= 0.0448 / (25 / 1000) \\ &= 1.79 \text{ mol/dm}^3 \end{aligned}$$

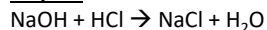
Example 12

What volume of 0.1M HCl is needed to neutralise 25.0cm³ of 0.14 mol/dm³ NaOH?

step 1: work out the number of moles of NaOH

$$\text{Number of moles} = \text{conc} \times \text{vol} = 0.14 \times 25.0 / 1000 = 0.0035 \text{ mol}$$

step 2: use the balanced equation to work out the moles of HCl



1 mole NaOH reacts with 1 mole HCl **1:1 ratio**

So 0.0035 moles NaOH reacts with 0.0035 moles HCl

Step 3: work out the volume of HCl

$$\begin{aligned} \text{volume} &= \text{moles} / \text{concentration} \\ &= 0.0035 / 0.1 \\ &= 0.035 \text{ dm}^3 \text{ or } 35 \text{ cm}^3 \end{aligned}$$

Gas Calculations

Chemistry only

Equal amounts in 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 24 dm³.

$$\text{Gas Volume (dm}^3\text{)} = \text{number of moles} \times 24$$

This equation gives the volume of a gas at room pressure (1atm) and room temperature 20°C.

Example 13 : Calculate the volume in dm³ at room temperature and pressure of 50.0g of carbon dioxide gas.

Step 1 convert mass to moles

$$\text{moles} = \text{mass}/M_r$$

$$= 50 / (12 + 16 \times 2)$$

$$= 1.136 \text{ mol}$$

Step 2 convert moles to gas volume

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

$$= 1.136 \times 24$$

$$= \text{or } 27.3 \text{ dm}^3 \text{ to 3 sig fig}$$

Example 14 : Calculate the mass of 500cm³ of chlorine gas (Cl₂) at room temperature and pressure.

Step 1 convert volume to dm³

$$500/1000 = 0.5\text{dm}^3$$

Step 2 convert gas volume to mole

$$\text{Moles} = \text{gas volume (dm}^3\text{)}/24$$

$$= 0.5 / 24$$

$$= 0.0208 \text{ mol to 3 sig fig}$$

Step 3 convert mole to mass

$$\text{mass} = \text{moles} \times M_r$$

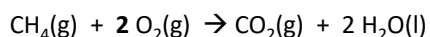
$$= 0.0208 \times (35.5 \times 2)$$

$$= 1.48\text{g to 3 sig fig}$$

Volumes of gases reacting in a balanced equation can also be calculated by simple mole ratio

Chemistry only

Example 15 If 500 cm³ of methane is burnt at 1atm, what volume of Oxygen would be needed and what volume of CO₂ would be given off under the same conditions?



1 mole 2 mole 1 mole

500cm³ 1dm³ 500cm³

Simply multiply gas volume x2 as 1:2 ratio in balanced equation

Combining equations

Chemistry only

1. For pure solids and gases

$$\text{moles} = \frac{\text{mass}}{M_r}$$

Unit of Mass: grams
Unit of moles : mol

2. For solutions

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

Unit of concentration: mol/dm³
Unit of Volume: dm³
Remember to convert cm³ into dm³

3. For gases

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

More complicated questions may require use of more than one of the above equations.
e.g. what mass of one substance may react with a volume and concentration of a solution

Step 1:

Use one of the above 3 equations to convert any given quantity into moles
Mass → moles
Volume of gas → moles
Conc and volume of solution → moles

Step 2:

Use balanced equation to convert moles of initial substance into moles of second substance

Step 3

Convert moles of second substance into quantity question asked for using relevant equation
e.g. Moles, M_r → mass
Mole gas → volume gas
Moles, vol solution → conc

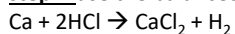
Example 15

Calculate the mass of calcium that would react with 25. cm³ of 2.0 mol/dm³ of hydrochloric acid

step 1: work out the number of moles of HCl

$$\text{Number of moles} = \text{conc} \times \text{vol} = 2 \times 25/1000 = 0.050 \text{ mol}$$

step2: use the balanced equation to work out the moles of Ca



2 mole HCl reacts with 1 mole Ca **2:1 ratio**

So 0.05 mol HCl reacts with 0.025 mol Ca

Step 3: calculate the mass of Ca

$$\begin{aligned} \text{Mass} &= \text{moles} \times M_r \\ &= 0.025 \times 40 \\ &= 1.0\text{g} \end{aligned}$$

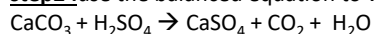
Example 16

Calculate the volume in dm³ of CO₂ gas produced if 3.0g of CaCO₃ reacts with excess H₂SO₄

step 1: work out the number of moles of CaCO₃

$$\text{Number of moles} = \text{mass}/M_r = 3/100 = 0.030 \text{ mol}$$

step2: use the balanced equation to work out the moles of CO₂



1 mole CaCO₃ forms 1 mole CO₂ **1:1 ratio**

So 0.030 mol CaCO₃ forms 0.030 mol CO₂

Step 3: calculate the volume of CO₂

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

$$\begin{aligned} &= 0.030 \times 24 \\ &= 0.72\text{dm}^3 \end{aligned}$$