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
  $CaCO_3$ + **2** HCl → $CaCl_2$ + H_2O + 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 Mg + O_2 → **2** 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 (*M*r) of a compound is the sum of the relative atomic masses (*A*r) of the atoms in the numbers shown in the formula.

Be able to work out the relative formula mass (*M*r) of a substance using data from the periodic table.
e.g. the *M*r of $CaCO_3$ = 40 + 12 + (16 x 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.
2Mg (s) + O_2 (g) → 2MgO (s)

In **thermal decompositions** of metal carbonates, carbon dioxide is produced which escapes into the atmosphere leaving the metal oxide as the only solid product.
$CaCO_3$ (s) → CaO (s)+ CO_2 (g)

Chemical measurements : uncertainty

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, 20.15
Mean = (20.10+ 20.20+ 20.00+ 20.05+ 20.15)/5 =20.10 cm^3
Uncertainty = ± 0.10 cm^3 (all readings are within ± 0.10 of mean)
The uncertainty might be written as 20.10 cm^3 ± 0.10 cm^3

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
moles = mass/*M*r or rearranged to **mass = *M*r x moles**

Example 1: Calculate the number of moles in 35.0g of $CuSO_4$

moles = mass/*Mr*

= 35.0/ (63.5 + 32 +16 x4)

= 0.219 mol

Many questions will involve changes of units
1000 mg =1g
1000 g =1 kg
1000 kg = 1 tonne

Example 2: Calculate the number of moles in 75.0mg of $CaSO_4.2H_2O$

moles = mass/*Mr*

= 0.075/ (40 + 32 +16 x4 + 18x2)

= 4.36×10^{-4} mol

Calculate the percentage by mass of an element in a compound

$$\textbf{percentage by mass} = \frac{\text{number of atoms of element x } Ar \text{ of element}}{Mr \text{ of compound}} \times 100$$

Example 3. Calculate the percentage by mass of oxygen in calcium sulfate ($CaSO_4$)

$$\textbf{percentage by mass} = \frac{\text{number of atoms of element x } Ar \text{ of element}}{Mr \text{ of compound}} \times 100$$

$$= \frac{4 \times 16}{(40 + 32 + 16\text{x}4)} \times 100$$

= 47 %

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 4 : Calculate the number of tin atoms in a 6.00 g sample of tin metal.

Step 1 calculate the number of moles

moles = mass/*Ar*

= 6/ 119

= 0.0504 mol

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

Number of atoms = moles x 6.02×10^{23}

= 0.0504 x 6.02×10^{23}

= 3.04×10^{22}

Example 5 : Calculate the number of chloride ions in a 9.50 g of magnesium chloride (*Mr* =95).

Step 1 calculate the number of moles of $MgCl_2$
moles = mass/*Mr*
= 9.5/ 95
= 0.1 mol

Step 2: Deduce moles of Cl^- ions = 2 x moles of $MgCl_2$
= 0.2

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

Number of ions = moles x 6.02×10^{23}

= 0.2 x 6.02×10^{23}

= 1.204×10^{23}

Example 6 : Calculate the mass of 1 atom of sodium
Mass of 1 atom = mass of 1 mole of sodium(*Ar*)/Avogadro's number
= 23/6.02×10^{23}
= 3.82×10^{-23} g

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:
$Mg + 2HCl \rightarrow MgCl_2 + H_2$
shows that one mole of magnesium reacts with two moles of hydrochloric acid to produce one mole of magnesium chloride and one mole of hydrogen gas.

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

Using $\text{number of moles} = \dfrac{\text{mass}}{M\text{r}}$

step2 : 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

Using mass = moles x *M*r

Example 7: Calculate the mass of carbon dioxide produced from heating 5.5 g of sodium hydrogencarbonate.
$2NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$

Step 1: work out moles of sodium hydrogencarbonate
moles = mass / *M*r
= 5.5 /84
= 0.0655 mol

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

Step 3: work out mass of CO_2
Mass = moles x *M*r
= 0.0328 x 44
=1.44 g

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 8. A sample of lead was heated strongly in oxygen. It was found that 8.28g of lead reacts with 0.64g of oxygen to form a lead oxide.
There are two possible lead oxides that could be formed: lead (II) oxide (PbO) and lead (IV) oxide (PbO_2)
Determine which is the correct equation.

Equation 1 $2Pb + O_2 \rightarrow 2PbO$
Equation 2 $Pb + O_2 \rightarrow PbO_2$

Step 1: calculate moles of each chemical whose mass if given
Moles of Pb = mass / *A*r
= 8.28 /207
= 0.04 mol

Moles of O_2 = mass / *M*r
= 0.64 /32
= 0.02 mol

Step 2: divide each moles in step 1 by the smallest number of moles to get a whole number ratio

Pb = 0.04/0.02
= 2

O_2 = 0.02/0.02
= 1

Step 3: choose the correct balanced equation:
$2Pb + O_2 \rightarrow 2PbO$

The whole number ratio in step 2 is the same as the balancing numbers in equation 1

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

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

step2 : 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: calculate the mass of the product
Using mass = moles x *M*r

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 9: 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?

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

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

Work out moles of Mg
Moles = mass /*A*r
= 5/24
= 0.208mol

Work out moles of O_2
Moles = mass /*M*r
= 6/32
= 0.188 mol

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

Using ratio of 2 Mg: 1 O_2 from balanced equation:

0.208 moles of Mg should react with 0.104 of O_2

but we have 0.188 mol of O_2 so O_2 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 O_2 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

Mass = moles x *M*r of MgO
= 0.208 x 40
= 8.32 g

Concentration calculations

The concentration of a solution can be measured in g/dm^3 or mol/dm^3.

Concentration(in mol/dm^3) = moles/volume (in dm^3)

Concentration(in g/dm^3) = mass (in g) /volume (in dm^3)

The volume in the above equation must be in **dm^3** . Volumes are often given in cm^3.
To **convert cm^3 into dm^3 divide by 1000**

Example 10: Calculate the concentration of a solution in g/dm^3 made by dissolving 500mg of $NaNO_3$ in 250 cm^3 water.

Convert units 500 mg= 0.50 g
250cm^3 = 0.25 dm^3

Conc in g/dm^3 = mass/volume
= 0.50 / **0.25**
= 2.0 g/dm^3

Example 11: Calculate the concentration in mol/dm^3 of a solution made by dissolving 5.00g of Na_2CO_3 in 250 cm^3 water.

moles = mass/*M*r
= 5.00 / (23 x2 + 12 +16 x3)
= 0.0472 mol

conc= moles/volume
= 0.0472 / **0.25**
= 0.189 mol/dm^3

Example 12 Calculate the mass of sodium chloride needed to make 100cm^3 of 0.100 mol/dm^3 NaCl solution.

moles= conc x volume
= 0.1 x **0.1**
= 0.01 mol

mass = mol x *M*r
= 0.01 x (23+35.5)
= 0.585 g

To convert a concentration in **g/dm^3** to **mol/dm^3** divide by ***M*r**

Example 13: A solution of HCl has a concentration of 1.825g/dm^3 . Calculate the concentration of the solution in mol/dm^3

Conc in mol/dm^3 = conc in g/dm^3 /*M*r
= 1.825 / 36.5
= 0.05 mol/dm^3

Required practical :Titrations

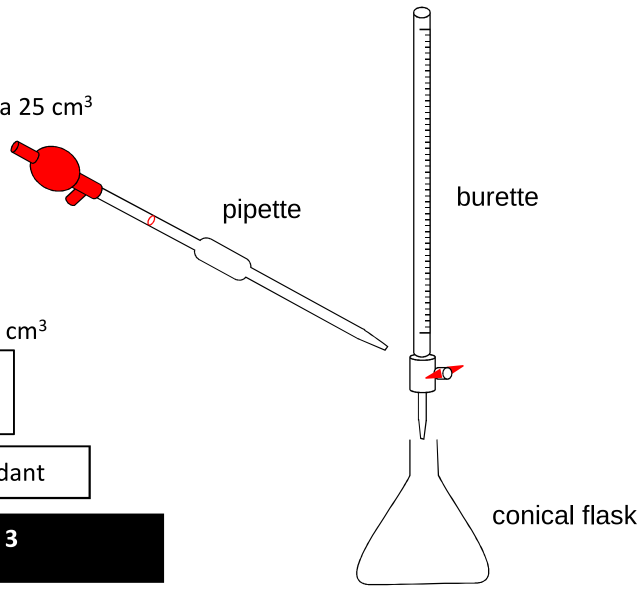
Chemistry only

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 25 cm^3 **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 0.1 cm^3



Common indicator: Phenolphthalein
Colour in acid: colourless   Colour in alkali: pink

Results within 0.10 cm^3 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

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 volume (in dm^3)**
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 ($NaOH + HCl \rightarrow NaCl + H_2O$)
Step 3: Calculate the concentration of the second substance
Using **concentration = moles / volume**

Example 14
25 cm^3 of HCl is reacted with 22.4cm^3 of 2 mol/dm^3 NaOH. Calculate the concentration of the HCl.

step 1: work out the number of moles of NaOH
Number of moles = conc x vol = 2 x 22.4/1000 = 0.0448 mol

step2 :use the balanced equation to work out the moles of HCl
$NaOH + HCl \rightarrow NaCl + H_2O$
1 mole NaOH reacts with 1 mole HCl **1:1 ratio**
So 0.0448 moles NaOH reacts with 0.0448 moles HCl

Step 3: calculate the conc of HCl
concentration = moles / volume
= 0.0448/ (25/1000)
= 1.79 mol/dm^3

Example 15
Calculate the volume of 0.1 mol/dm^3 HCl needed to neutralise 25.0cm^3 of 0.14 mol/dm^3 NaOH.

step 1: work out the number of moles of NaOH
Number of moles = conc x vol = 0.14 x 25.0/1000 = 0.0035 mol

step2 : use the balanced equation to work out the moles of HCl
$NaOH + HCl \rightarrow NaCl + H_2O$
1 mole NaOH reacts with 1 mole HCl **1:1 ratio**
So 0.0035 moles NaOH reacts with 0.0035 moles HCl

Step 3: calculate the volume of HCl
volume= moles / concentration
= 0.0035/ 0.1
= 0.035 dm^3 or 35 cm^3

Chemistry only

Percentage Yield

Even though no atoms are gained or lost in a chemical reaction, it is not always possible to obtain the calculated amount of 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 16: 25.0 g of Fe_2O_3 was reacted and it produced 10.0 g of Fe. Calculate the percentage yield.

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

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

Step 1: work out moles of iron oxide
Moles = mass / *Mr*
=25.0 / 160
= 0.156 mol

Step 2: use balanced equation to give moles of Fe
1 moles Fe_2O_3 : 2 moles Fe
So 0.156 Fe_2O_3 : 0.313moles Fe

Step 3: calculate maximum mass of Fe
Mass = moles x *Ar*
= 0.313 x 56
= 17.5 g

Step 4: calculate the percentage yield

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

= (10/ 17.5) x 100

= 57.1%

Percentage atom economy

Chemistry only

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 17: Calculate the % atom economy for the following reaction where Fe is the desired product assuming the reaction goes to completion.

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

$$\% \text{ atom economy} = \frac{(2 \times 56)}{(2 \times 56 + 3\times16) + 3 \times (12+16)} \times 100$$

=45.9%

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 dm^3.

Gas volume (dm^3) = number of moles x 24

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

Example 18 : Calculate the volume in dm^3 at room temperature and pressure of 50.0 g of carbon dioxide gas.

Step 1 convert mass to moles

moles = mass/*Mr*

= 50/ (12 + 16 x2)

= 1.136 mol

Step 2 convert moles to gas volume

Gas volume (dm^3)= moles x 24

= 1.136 x 24

= or 27.3 dm^3 to 3 sig fig

Example 19 : Calculate the mass of 500 cm^3 of chlorine gas (Cl_2) at room temperature and pressure.

Step 1 convert volume to dm^3

500/1000 = 0.5 dm^3

Step 2 convert gas volume to moles

moles = gas volume (dm^3)/24

= 0.5 /24

= 0.0208 mol to 3 sig fig

Step 3 convert mole to mass

mass = moles x *Mr*

= 0.0208 x (35.5x2)

= 1.48 g to 3 sig fig

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

Chemistry only

Example 20 If 500 cm^3 of methane is burnt at room temperature and pressure, what volume of oxygen would be needed and what volume of CO_2 would be given off under the same conditions?

$CH_4(g)$ + **2** $O_2(g)$ → $CO_2(g)$ + 2 $H_2O(l)$

1 mole	**2** mole	1 mole
500cm^3	1dm^3	500cm^3

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

Combining equations

Chemistry only

1. For pure solids and gases

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

Unit of mass: grams
Unit of moles : mol

2. For solutions

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

Unit of concentration: mol/dm^3
Unit of volume: **dm^3**
Remember to convert cm^3 into dm^3

3. For gases

Gas volume (dm^3)= moles x 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 ,*Mr* → mass
Mole gas → volume gas
Moles, vol solution → conc

Example 21
Calculate the mass of calcium that would react with 25.0 cm^3 of 2.0 mol/dm^3 of hydrochloric acid.

<u>step 1</u>: Calculate the number of moles of HCl
Number of moles = conc x vol = 2 x 25/1000 = 0.050 mol

<u>step2</u> : Use the balanced equation to work out the moles of Ca
$Ca + 2\ HCl \rightarrow CaCl_2 + H_2$
2 mole HCl reacts with 1 mole Ca **2:1 ratio**
So 0.05 mol HCl reacts with 0.025 mol Ca

<u>Step 3</u>: Calculate the mass of Ca
Mass = moles x *Mr*
= 0.025 x40
= 1.0g

Example 22
Calculate the volume in dm^3 of CO_2 gas produced if 3.0 g of $CaCO_3$ reacts with excess H_2SO_4

<u>step 1</u>: Calculate the number of moles of $CaCO_3$
Number of moles = mass/*Mr*= 3/100 = 0.030 mol

<u>step2</u> : Use the balanced equation to work out the moles of CO_2
$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + CO_2 + H_2O$
1 mole $CaCO_3$ forms 1 mole CO_2 **1:1 ratio**
So 0.030 mol $CaCO_3$ forms 0.030 mol CO_2

<u>Step 3</u>: Calculate the volume of CO_2
Gas volume (dm^3)= moles x 24
= 0.030 x24
= 0.72dm^3