

Quantitative chemistry

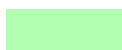
Specification 8462 · AQA

Free edition

Revision notes for one topic, free to download.

These are the summary notes only. The full edition of this booklet also carries the worked examples, the required practicals and the formula sheets, with every topic in one place.

Colour Codes



Definitions



Notes and warnings



Sub-topic headings

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Define Law of conservation of mass

- no atoms are lost or made in a chemical reaction, so the mass of the products equals the mass of the reactants.

Define Relative formula mass (M_r)

- the sum of the relative atomic masses of the atoms in the numbers shown in the formula.

Define Range

- largest value minus smallest value in a set of repeats.

HIGHER TIER

Define HT ONLY Avogadro constant

- the number of atoms, molecules or ions in one mole of a substance, 6.02×10^{23} per mole.

HIGHER TIER

Define HT ONLY Excess reactant

- a reactant added in more than enough quantity so the other reactant is all used up.

Define CHEMISTRY ONLY Yield

- the amount of product actually obtained from a reaction.

Define CHEMISTRY ONLY Atom economy (atom utilisation)

- a measure of the amount of the starting materials that end up as useful products.

HIGHER TIER

Define CHEMISTRY ONLY HT ONLY Molar gas volume

- the volume of one mole of any gas at room temperature and pressure, 24 dm^3 .

Define Relative atomic mass (A_r)

- an average value that takes account of the abundance of the isotopes of the element; read from the periodic table.

Define Uncertainty

- how far a measured value could differ from the true value, estimated from the range of repeats.

HIGHER TIER

Define HT ONLY Mole (mol)

- the unit of chemical amount; one mole has a mass in grams numerically equal to the M_r .

HIGHER TIER

Define HT ONLY Limiting reactant

- the reactant completely used up, which therefore limits the amount of product formed.

HIGHER TIER

Define Concentration

- the amount of solute in a given volume of solution (g/dm^3 , or **CHEMISTRY ONLY HT ONLY** mol/dm^3).

Define CHEMISTRY ONLY Percentage yield

- the mass of product actually made as a percentage of the maximum theoretical mass.

Define CHEMISTRY ONLY Titration

- finding the volumes of acid and alkali that react exactly, used to find an unknown concentration.

HIGHER TIER

Define CHEMISTRY ONLY HT ONLY Room temperature and pressure (rtp)

- 20°C and 1 atmosphere pressure.

3.1 Chemical measurements, conservation of mass and the quantitative interpretation of chemical equations

3.1.1 Conservation of mass and balanced chemical equations

- The **law of conservation of mass**: no atoms are lost or made during a chemical reaction, so the mass of the products equals the mass of the reactants. Atoms are only rearranged.
- So reactions can be represented by symbol equations balanced in terms of the number of atoms of each element on both sides.
- A multiplier in normal script before a formula ($2\text{H}_2\text{O}$) multiplies everything in that formula — 4 H and 2 O atoms. A **subscript within a formula** (H_2O) applies only to the atom it follows and is part of the substance's identity. When balancing, change only the multipliers in front.

WATCH OUT

Students often "fix" an equation by changing a subscript, writing H_2O_2 for H_2O . **Never change a subscript** — H_2O_2 is hydrogen peroxide, a different substance. Change only the large numbers in front.

3.1.2 Relative formula mass

- The **relative formula mass (Mr)** is the sum of the relative atomic masses of the atoms in the numbers shown in the formula. Ar values are on the **periodic table** given in the exam.
- Brackets multiply everything inside: $\text{Ca}(\text{NO}_3)_2$ contains 1 Ca, 2 N and 6 O.
- Comparing Mr on both sides checks conservation of mass: for $4\text{Al} + 3\text{O}_2 \rightarrow 2\text{Al}_2\text{O}_3$, reactants $(4 \times 27) + (3 \times 32) = 204$ and products $2 \times 102 = 204$.

3.1.3 Mass changes when a reactant or product is a gas

- Some reactions appear to involve a change in mass. This can usually be explained because a reactant or product is a gas whose mass has not been taken into account — the system is not enclosed, so gas can leave or enter.
- Mass appears to increase when a gas is a **reactant**: when a metal reacts with oxygen, the mass of the oxide is greater than the mass of the metal, because oxygen atoms from the air have joined the solid.
- Mass appears to decrease when a gas is a **product**: in the **thermal decomposition of metal carbonates**, carbon dioxide is produced and escapes into the atmosphere, leaving the metal oxide as the only solid product.
- **Particle model**: the gas particles spread out into the surroundings and are no longer on the balance. No atoms are created or destroyed — in a sealed container the total mass would not change.

3.1.4 Chemical measurements

- Whenever a measurement is made there is always some uncertainty about the result obtained.
- Repeat the measurement, discard any **anomalous** result, then take the **mean** of the rest.
- The **distribution (spread) of results** shows their precision: closely grouped = low uncertainty; widely spread = high uncertainty.
- Use the range of a set of measurements about the mean as the measure of uncertainty, quoted as $\pm$ **half the range**.

3.2 Use of amount of substance in relation to masses of pure substances

HIGHER TIER

3.2.1 HT ONLY Moles

- **HT ONLY** Chemical amounts are measured in **moles**; the symbol for the unit mole is **mol**.
- **HT ONLY** The mass of one mole of a substance in grams is numerically equal to its relative formula mass — one mole of carbon is 12 g, one mole of water is 18 g.
- **HT ONLY** One mole of a substance contains the same number of the stated particles — atoms, molecules or ions — as one mole of any other substance. That number is the Avogadro constant, 6.02×10^{23} per mole.
- **HT ONLY** Moles apply to atoms, molecules, ions, electrons, formulae and equations: one mole of carbon (C) contains the same number of atoms as there are molecules in one mole of carbon dioxide (CO₂).

HIGHER TIER

3.2.2 HT ONLY Amounts of substances in equations

- **HT ONLY** The masses of reactants and products can be calculated from balanced symbol equations.
- **HT ONLY** Equations can be interpreted in terms of moles: $\text{Mg} + 2\text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2$ 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.
- **HT ONLY** Route for any reacting-mass question: **mass** → **moles** ($n = m \div \text{Mr}$) → ratio from the balanced equation → **moles** → **mass** ($m = n \times \text{Mr}$).

ANALOGY

Making **cheese sandwiches**, each needing 2 slices of bread and 1 slice of cheese: with 10 slices of bread and 8 of cheese you can make only 5 sandwiches. The bread runs out first, so bread is **limiting** and 3 slices of cheese are left in excess. Buying more cheese gets you no extra sandwiches.

HIGHER TIER

3.2.5 Concentration of solutions

- Many reactions take place **in solution**. Concentration can be measured as mass of solute per given volume of solution, e.g. **grams per dm³ (g/dm³)**.
- $1 \text{ dm}^3 = 1000 \text{ cm}^3 = 1 \text{ litre}$; convert cm^3 to dm^3 by **dividing by 1000**.
- **HT ONLY** Concentration depends on both the mass of solute and the volume of solution: it increases if more solute is dissolved in the same volume and decreases if the same mass is dissolved in a larger volume (diluting).

ANALOGY

A mole is the chemist's "dozen". A dozen eggs and a dozen bricks both contain 12 things but have very different masses. Likewise one mole of C and one mole of CO₂ both contain 6.02×10^{23} particles but weigh 12 g and 44 g. The mole is just a counting number, chosen so the count in grams matches the Mr.

WATCH OUT

Moles are not mass. A mole is a *count* of particles; a gram is a *mass*. One mole of H₂ weighs 2 g and one mole of I₂ weighs 254 g — same number of molecules, hugely different masses. Always convert mass to moles before using the ratio in a balanced equation, and back to mass at the end; never put masses straight into the ratio.

HIGHER TIER

3.2.3 HT ONLY Using moles to balance equations

- **HT ONLY** The balancing numbers can be calculated from the masses of reactants and products by converting the masses in grams to amounts in moles, then converting the numbers of moles to a **simple whole number ratio**.

HIGHER TIER

3.2.4 HT ONLY Limiting reactants

- **HT ONLY** In a reaction with two reactants it is common to use an excess of one to make sure all of the other is used up.
- **HT ONLY** The reactant **completely used up** is the **limiting reactant**, because it limits the amount of product.
- **HT ONLY** The amount of product is proportional to the amount of limiting reactant; adding more of the excess reactant makes no difference.
- **HT ONLY** To identify it, divide the moles of each reactant by its balancing number — the smallest answer is limiting.

3.3 CHEMISTRY ONLY Yield and atom economy of chemical reactions

HIGHER TIER

3.3.1 CHEMISTRY ONLY Percentage yield

- **CHEMISTRY ONLY** Even though no atoms are gained or lost, 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.
- **CHEMISTRY ONLY** The amount of product obtained is the **yield**; compared with the **maximum theoretical amount** as a percentage it is the **percentage yield**. It can never exceed 100 % — a higher value means the product is impure or not fully dry.

ANALOGY

Atom economy is about the design of the reaction; percentage yield is about how well the experiment went. Making a chair from a plank: **atom economy** is the fraction of the plank that becomes chair rather than sawdust — fixed by the design, calculable on paper before you start. Percentage yield is how much chair you actually end up with after mis-cuts and dropped pieces — known only after doing the job.

3.3.2 CHEMISTRY ONLY Atom economy

- **CHEMISTRY ONLY** The **atom economy (atom utilisation)** measures the amount of the starting materials that end up as useful products.
- **CHEMISTRY ONLY** It is important for sustainable development and for economic reasons to use reactions with a high atom economy: less waste, fewer raw materials used up, lower separation and disposal costs. A reaction with only one product has an atom economy of **100 %**.
- **CHEMISTRY ONLY HT ONLY** You may be asked to explain why a particular reaction pathway is chosen to produce a specified product, given data such as atom economy, yield, rate, position of equilibrium and the usefulness of by-products. A pathway with a lower atom economy may still be chosen if it is faster, gives a higher yield, or its by-products can be sold.

WATCH OUT

Percentage yield and atom economy are different. - Percentage yield compares the **mass actually made** with the **maximum theoretical mass**; it depends on the practical work, so it is known only after the experiment. - Atom economy compares the **Mr of the desired product** with the **total Mr of the reactants**; it depends only on the **balanced equation**, so it can be worked out before doing anything. - A one-product reaction always has 100 % atom economy but may still give a poor yield; a reaction with many by-products has a low atom economy even at 100 % yield.

3.4 CHEMISTRY ONLY

HT ONLY Using concentrations of solutions in mol/dm³

HIGHER TIER

- **CHEMISTRY ONLY HT ONLY** Concentration can also be measured in mol/dm^3 — the moles of solute in 1 dm^3 of solution.
- **CHEMISTRY ONLY HT ONLY** The amount in moles, or the mass in grams, of solute in a given volume of solution can be calculated from its concentration in mol/dm^3 .
- **CHEMISTRY ONLY HT ONLY** Concentration increases with more moles of solute in the same volume and decreases if the solution is made up to a larger volume. Multiply by the M_r to convert mol/dm^3 into g/dm^3 .
- **CHEMISTRY ONLY HT ONLY** If the volumes of two solutions that react completely are known and the concentration of one is known, the concentration of the other can be calculated — this is what a **titration** does.

HIGHER TIER

NOTE

Cross-reference — Required practical 2 CHEMISTRY ONLY. The titration practical (determination of the reacting volumes of solutions of a strong acid and a strong alkali by titration, and **HT ONLY** determination of the concentration of one of the solutions in mol/dm^3 and g/dm^3 from the reacting volumes and the known concentration of the other) is written up in Topic 4, Chemical changes. The calculation it depends on is the one above; remember that only concordant titres are averaged and the uncertainty in the mean titre is $\pm$ **half the range** (3.1.4).

3.5 CHEMISTRY ONLY

HT ONLY Use of amount of substance in relation to volumes of gases

HIGHER TIER

- **CHEMISTRY ONLY HT ONLY** Equal amounts in moles of gases occupy the same volume under the same conditions of temperature and pressure — the identity of the gas makes no difference.
- **CHEMISTRY ONLY HT ONLY** The volume of one mole of any gas at room temperature and pressure (20°C and 1 atmosphere pressure) is 24 dm^3 ($24\,000 \text{ cm}^3$).
- **CHEMISTRY ONLY HT ONLY** The volumes of gaseous reactants and products can be calculated from the balanced equation. Because equal moles occupy equal volumes, the balancing numbers give the ratio of gas volumes directly.