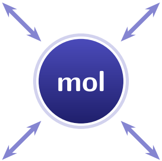
Atoms, Molecules & Stoichiometry

A-Level Chemistry ▪ Topic 2

A-Level Chemistry



What we will cover

1. Relative masses
2. The mole
3. Formulas & equations
4. Reacting masses & yield
5. Gas volumes
6. Titration

mass is the basis

1 Masses and the mole

Relative masses

Masses are compared with $\frac{1}{12}$ of a ^{12}C atom (the unified atomic mass unit, u).

A_r
相对原子质量
average mass of an element's atoms – weighted over its isotopes

M_r
相对分子质量
sum of the A_r values of every atom in the molecule

formula mass
相对式量
the same idea for an ionic compound

Chlorine is 75% ^{35}Cl and 25% ^{37}Cl

$A_r = (75 \times 35 + 25 \times 37)/100 = 35.5$

Four relative masses, one reference atom

Relative isotopic mass	The mass of one atom of a *single* isotope, against $\frac{1}{12}$ of a carbon-12 atom.
Relative atomic mass	A_r: the weighted average over the isotopes as they occur – which is why it is rarely a whole number.
Relative molecular mass	M_r of a **molecule 分子**: the sum of the relative atomic masses of all its atoms.
Relative formula mass	The same idea for a substance not made of molecules – an ionic compound, where there is no molecule to weigh.
The Avogadro constant	6.02×10^{23} mol^{-1}: how many particles are in a mole, and what turns any of these masses into a count.

All four are ratios against the same standard, so they carry no units. Only the Avogadro constant does.

The mole

$$n = \frac{m}{M}$$

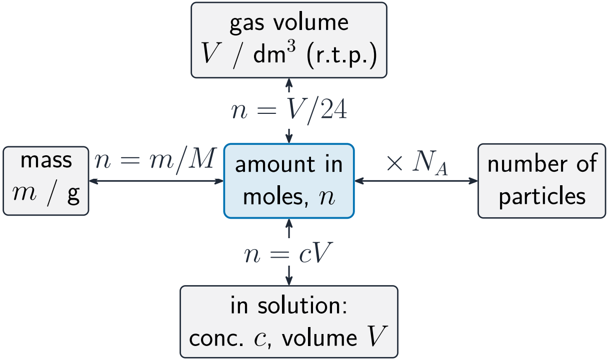
$$N_A = 6.02 \times 10^{23}\,\mathrm{mol^{-1}}$$

Worked example

moles in $8.0\,\mathrm{g}$ of CH_4 $(M = 16)$: $n = \frac{8.0}{16} = 0.50\,\mathrm{mol}$

One **mole** 摩尔 contains N_A particles (atoms, molecules *or* ions); the **molar mass** 摩尔质量 M in $\mathrm{g\,mol^{-1}}$ equals A_r or M_r.

The mole map



A **compound** 化合物 is two or more elements chemically joined. Chemists count its particles in moles, as we count eggs in dozens – the hub of every amount calculation:

- mass: $n = m/M$
- particles: $\times N_A$
- gas: $n = V/24$
- solution: $n = cV$

2 Formulas and reacting masses

Formulas and equations

empirical formula 实验式

simplest ratio – CH_3

molecular formula 分子式

actual atoms – C_2H_6

Equations are **balanced** 配平 with **state symbols** 状态符号 (s, l, g, aq). An **ionic equation** 离子方程式 drops **spectator ions** 旁观离子: $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$.

Formulas and equations, in detail

element	% by mass	$\div A_r \to$ moles	$\div$ smallest (3.33)	ratio
C	40.0	$40.0/12 = 3.33$	1.0	1
H	6.7	$6.7/1 = 6.7$	2.0	2
O	53.3	$53.3/16 = 3.33$	1.0	1

empirical formula CH_2O - if $M_r = 180$, it fits $180/30 = 6$ times: molecular formula $C_6H_{12}O_6$

> The empirical-formula recipe: divide by Ar, divide by the smallest, read off the ratio

Hydrated and anhydrous solids

Some solids hold water inside their crystals.

This water is the **water of crystallisation 结晶水**.

Reacting masses and yield

Worked example: $2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$

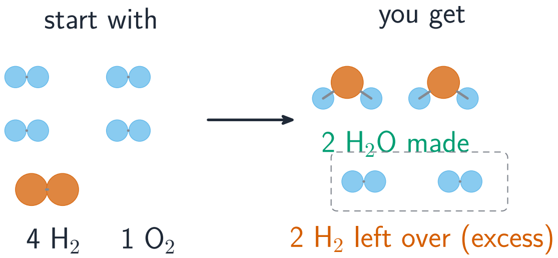
$4.8\,\text{g}$ Mg $= 0.20\,\text{mol}$; ratio $1:1 \Rightarrow 0.20\,\text{mol}$ MgO $= 0.20 \times 40 = 8.0\,\text{g}$

$$\text{percentage yield} = \frac{\text{actual product}}{\text{maximum possible}} \times 100\%$$

The numbers in a balanced equation give the mole ratio – the **stoichiometry** 化学计量.

Limiting reagent

$$2\mathbf{H}_2 + \mathbf{O}_2 \rightarrow 2\mathbf{H}_2\mathbf{O}$$



O_2 runs out first:
limiting reagent

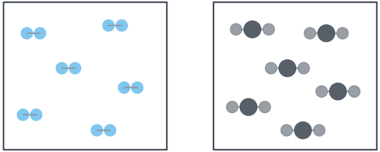
The **limiting reagent** 限量试剂 runs out first and decides how much product forms.

> The leftover reactant is in **excess** 过量试剂. Always base the calculation on the limiting reagent.

3 Gases and solutions

Gas volumes

same volume, same temperature and pressure



hydrogen, H_2 carbon dioxide, CO_2

the same **number** of molecules (6 each), even though CO_2 is bigger

Equal volumes of any gases (same temperature & pressure) hold equal numbers of molecules.

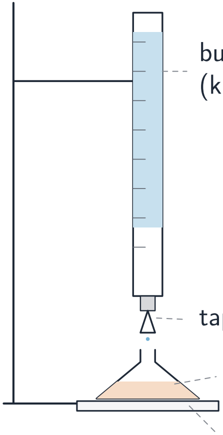
> At r.t.p., one mole of any gas is $24.0\,\mathrm{dm}^3$, so $n = \frac{V}{24.0}$.

The words a solution question uses

Solute and solution	Concentration is the amount of **solute** 溶质 in each cubic decimetre of **solution** 溶液, in mol dm^{-3}: $c = n/V$.
State symbols	(s) solid, (l) liquid, (g) gas, and (aq) **aqueous** 水溶液 – dissolved in water. An equation without them is incomplete.
Excess reagent	The **limiting reagent** 限量试剂 runs out first and fixes the yield; whatever is left over is the **excess reagent** 过量试剂.
Hydrocarbons	For burning **hydrocarbons** 碳氢化合物 – compounds of carbon and hydrogen only – compare *gas volumes* directly, since equal volumes hold equal moles.

> Convert to moles first, every time. Mass, concentration and gas volume are three doors into the same room.

Titration



Concentration 浓度: $n = c \times V$ (in $\mathrm{mol\,dm^{-3}}$, V in $\mathrm{dm^3}$).

NaOH neutralised by HCl

$20.0\,\mathrm{cm^3}$ of $0.100\,\mathrm{mol\,dm^{-3}}$ HCl $\Rightarrow$ NaOH $= 0.0800\,\mathrm{mol\,dm^{-3}}$

A **titration** 滴定 finds an unknown concentration.

Reacting masses and percentage yield

mole ratio $1:1$

$\div\, A_r\ (24)$ $\quad$ $(2\,\mathrm{Mg} + \mathrm{O_2} \longrightarrow 2\,\mathrm{MgO})$ $\quad$ $\times\, M_r\ (40)$

4.8 g of Mg $\rightarrow$ 0.20 mol Mg $\rightarrow$ 0.20 mol MgO $\rightarrow$ 8.0 g of MgO

mass $\rightarrow$ moles $\rightarrow$ use the equation's ratio $\rightarrow$ moles $\rightarrow$ mass

> The mole bridge: mass to moles, ratio, then back to mass

Relative masses of atoms and molecules

$$A_r = \frac{(75 \times 35) + (25 \times 37)}{100} = 35.5$$

Relative atomic mass is a weighted average over the isotopes – chlorine is 75% ^{35}Cl and 25% ^{37}Cl, so $A_r = 35.5$. **Atoms** 原子 are far too light to weigh in grams, so every mass is compared to $\frac{1}{12}$ of a ^{12}C atom – the **unified atomic mass unit** 统一原子质量单位, u.

Predicting an ion's charge from the group

In an **ionic compound** 离子化合物 the positive and negative charges balance exactly, so the compound is neutral overall.

Group	1	2	13	15	16	17
Ion charge	$+1$	$+2$	$+3$	-3	-2	-1

Hydrogen forms H^+; the Group 18 noble gases do not normally form ions at all. Where a metal has more than one charge, a Roman numeral gives the **oxidation number** 氧化数: iron(II) is Fe^{2+}, iron(III) is Fe^{3+}.

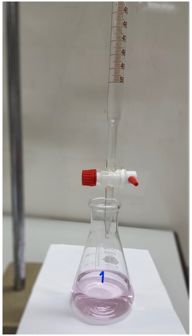
Worked example – the A_r of copper

A mass spectrometer shows copper is 69.2% ^{63}Cu and 30.8% ^{65}Cu

$$A_r = \frac{(69.2 \times 63) + (30.8 \times 65)}{100} = \frac{4359.6 + 2002.0}{100} = 63.6$$

Multiply each isotope's mass by its abundance, add, divide by 100. The answer always sits between the isotope masses, nearer the commoner one – which is how you check it.

Reacting masses and volumes



A titration finds reacting volumes precisely.

Exam tips

- Convert volumes to dm^3 **before** using concentration (25.0 cm^3 $= 0.0250$ dm^3); the missing $\div 1000$ is the most common titration error.
- Use the **balancing numbers** as the mole ratio between species – never the M_r values.
- Empirical formula: divide each mass/percentage by A_r, then by the **smallest**, then scale to whole numbers; use M_r to reach the molecular formula.
- For gases at r.t.p. use volume $=$ moles $\times$ 24 dm^3; quote the equation you use every time.
- Give the answer to the same **significant figures** as the data (usually 3) and always include units.

4 Recap

Topic 2 – key takeaways

1 The mole

$n = m/M$; $N_A = 6.02 \times 10^{23}$

2 Formulas

empirical (ratio) vs molecular (actual)

3 Reacting masses

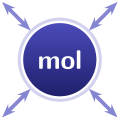
use the mole ratio; limiting reagent

4 Gases & solutions

$n = V/24$ at r.t.p.; $n = cV$

Check yourself

1. How many moles in 16 g of CH_4?
2. Empirical formula of C_2H_6?
3. What volume does 1 mol of gas occupy at r.t.p.?
4. Which reagent decides how much product forms?



Answers **1.** 1 mol **2.** CH_3 **3.** $24.0\,\mathrm{dm}^3$ **4.** the limiting reagent