Stoichiometry

IGCSE Chemistry ▪ Topic 3

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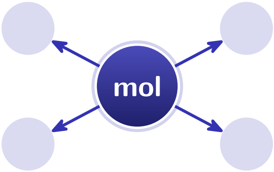


What we will cover

1 Formulae & equations

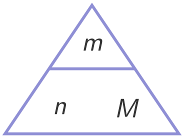
2 The mole & molar mass

3 Gas volumes & concentration

4 Reaction calculations

5 Limiting reactant & titration

6 Empirical formulae & percentages



$n = m/M$

the mole and molar mass

1 Formulae and equations

Chemical formulae

Al^{3+} O^{2-} gives $\mathrm{Al_2O_3}$

2 **3**

the charge numbers cross over to become the subscripts (then simplify if they share a factor)

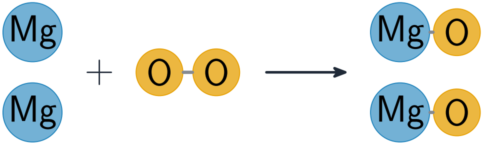
- The **molecular formula** 分子式 is the actual number of each atom in one **molecule** 分子. For glucose it is $\mathrm{C_6H_{12}O_6}$.
- The **empirical formula** 实验式 is the simplest whole-number **ratio** 比例 of the atoms or **ions** 离子 in a **compound** 化合物. For glucose it is $\mathrm{CH_2O}$.

Formulae, equations and state symbols

an ionic compound 离子化合物	work the formula out from the charges: total positive must balance total negative
the common ions	+: Na^+, K^+, Ca^{2+}, Mg^{2+}, Al^{3+}, NH_4^+. −: Cl^-, OH^-, NO_3^-, SO_4^{2-}, CO_3^{2-}, O^{2-}
a word equation 文字方程式	uses names: *magnesium* + *oxygen* → *magnesium oxide*
a symbol equation	uses formulae, and must be balanced
state symbols 状态符号	(*s*) solid, (*l*) liquid, (*g*) gas, (*aq*) **aqueous 水溶液** – dissolved in water
an ionic equation 离子方程式	shows only the ions that actually change; spectator ions are left out

Balance by changing the numbers in front, never the formulae themselves. Changing a subscript makes it a different substance.

Writing and balancing equations



$$2\mathrm{Mg} + \mathrm{O_2} \rightarrow 2\mathrm{MgO}$$

2 Mg and 2 O on each side: balanced

A **balanced** 配平 symbol equation has the same number of each atom on both sides.

$$2\mathrm{Mg} + \mathrm{O_2} \rightarrow 2\mathrm{MgO}$$

State symbols 状态符号: (*s*) (*l*) (*g*) (*aq*).

The words an equation uses

Reactants	The **reactants** 反应物 are on the left – what you start with.
Products	The **products** 生成物 are on the right – what you finish with.
Balancing	Change the *numbers in front*, never the formulas. Atoms are conserved, so each element must appear the same number of times on both sides.
In solution	A **solute** 溶质 dissolves in a solvent to give a solution; concentration is moles of solute per dm^3.

> A balanced equation is a recipe in *moles*, which is why every reacting-mass calculation begins by writing one.

2 The mole

The mole and molar mass

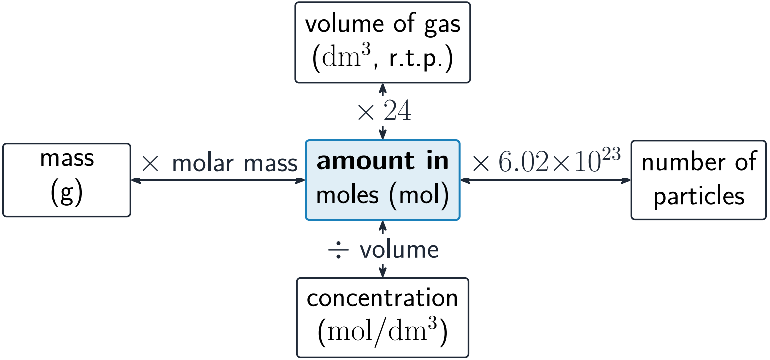
One **mole** 摩尔 $= 6.02 \times 10^{23}$ particles (the **Avogadro constant** 阿伏伽德罗常数).

$$n = \frac{\text{mass}}{\text{molar mass}}$$

Example

36 g of water: $n = \dfrac{36}{18} = 2$ mol.

The mole and molar mass, in detail



> One **mole** 摩尔 $= 6.02\times10^{23}$ particles (the **Avogadro constant** 阿伏伽德罗常数).

Gas volumes and concentration

At r.t.p. one mole of any gas fills 24 dm^3.

$V = n \times 24$

Example

0.25 mol CO_2: $V = 0.25 \times 24 = 6\ \text{dm}^3$.

$$\text{conc}\ (\text{mol}/\text{dm}^3) = \frac{n}{V(\text{dm}^3)}$$

Convert volume first: $1\ \text{dm}^3 = 1000\ \text{cm}^3$.

Reaction calculations

Three steps:

1. known mass $\rightarrow$ moles
2. use the equation ratio
3. moles $\rightarrow$ mass / volume

12 g Mg burns: mass of MgO?

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

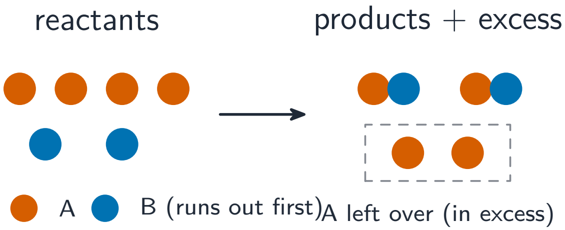
moles Mg $= 12/24 = 0.5$

ratio $1{:}1 \Rightarrow 0.5$ mol MgO

mass $= 0.5 \times 40 = \mathbf{20}$ g

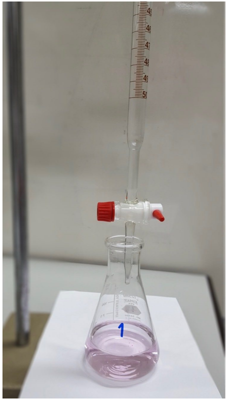
3 Applications

Limiting reactant



The **limiting reactant** 限量反应物 runs out first and decides how much product forms. The other reactant is left over **in excess** 过量.

Titration



25.0 cm^3 NaOH neutralised by 20.0 cm^3 of 0.10 HCl

$$\text{moles HCl} = 0.10 \times \frac{20.0}{1000} = 0.0020$$

$$\text{ratio } 1{:}1 \Rightarrow 0.0020 \text{ mol NaOH}$$

$$\text{conc} = \frac{0.0020}{25.0/1000} = \mathbf{0.08}\ \text{mol/dm}^{\mathbf{3}}$$

A titration measures exactly how much acid reacts with a base.

Empirical formula and percentages

$$\% \text{ by mass} = \frac{\text{mass of element}}{M_r} \times 100$$

40% Ca, 12% C, 48% O

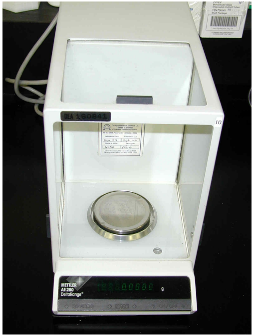
$\div A_r$: $1, \ 1, \ 3$

ratio $1{:}1{:}3 \Rightarrow \mathbf{CaCO_3}$

% N in NH_4NO_3

$$\frac{28}{80} \times 100 = \mathbf{35}\%$$

Relative masses



A laboratory balance measures mass – the basis of mole calculations.

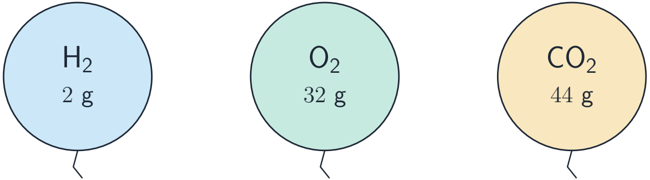
The masses, and the amount of substance

Relative atomic mass	A_r: the average mass of an atom of an element, against $\frac{1}{12}$ of a carbon-12 atom.
Relative molecular mass	**Relative molecular mass** 相对分子质量 M_r: the A_r values of every atom in the molecule, added.
Relative formula mass	**Relative formula mass** 相对式量: the same sum for something with no molecules – an ionic compound such as NaCl.
Amount of substance	The **amount of substance** 物质的量 is measured in *moles*: $n = m/M_r$, and one mole is 6.02×10^{23} particles.
Molar gas volume	The **molar gas volume** 摩尔气体体积: one mole of any gas occupies $24\ \text{dm}^3$ at room temperature and pressure.

Percentage composition by mass 质量百分组成 is $\dfrac{\text{mass of that element}}{M_r} \times 100$ – the same arithmetic, read the other way.

Volumes of gases

one mole of any gas at r.t.p.



different masses, the **same volume**: 24 dm^3 each

volume (dm^3) $=$ moles $\times\ 24$

> One mole of any gas fills 24 cubic decimetres at room temperature and pressure

Titration calculation

ratio $1:1$

from the equation

$n = c \times \frac{V}{1000}$

$c = \frac{n}{V}$

known acid
20.0 cm^3 of
0.10 mol/dm^3 HCl

→

moles of HCl
$0.10 \times \frac{20.0}{1000}$
$= 0.0020$ mol

→

moles of NaOH
$= 0.0020$ mol

←

concentration
$\frac{0.0020}{0.0250} = 0.08$
mol/dm^3

it is in 25.0 cm^3 of the NaOH solution, so divide by 0.0250 dm^3

> The titration calculation: known solution to moles, ratio, then the unknown concentration

Exam tips

- Always turn masses, gas volumes and concentrations into **moles** first, use the balanced equation's ratio, then convert back. Never compare masses directly across an equation.
- Key formulas: $n = \frac{\text{mass}}{M_r}$, gas volume $= n \times 24\ \text{dm}^3$ at r.t.p., and concentration $= \frac{n}{\text{volume in dm}^3}$. Change cm^3 to dm^3 by dividing by 1000.
- To balance a symbol equation you may only change the big numbers *in front* of a formula, never the small subscripts inside it.
- The **limiting reactant** is the one that runs out (fewest moles once you allow for the ratio); it sets how much product forms. The other reactant is in excess.
- **Percentage yield** $=$ actual $\div$ theoretical $\times$ 100; **percentage purity** $=$ mass of pure substance $\div$ mass of sample $\times$ 100. Both are always 100% or less.

4 Recap

Topic 3 – key takeaways

1 Mole

n = mass / molar mass; 6.02×10^{23}

2 Gas & conc

$24\ \mathrm{dm}^3$ per mole; conc = n/V

3 Calculations

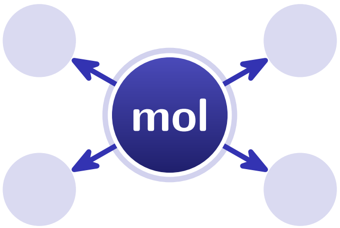
to moles, use the ratio, back again

4 Limiting

the reactant that runs out sets the yield

Check yourself

1. How many moles are in 18 g of water?
2. What volume does 1 mol of gas fill at r.t.p.?
3. What is a spectator ion?
4. How do you find an empirical formula from masses?



Answers **1.** 1 mol **2.** 24 dm^3 **3.** an ion unchanged on both sides **4.** divide each mass by A_r, then by the smallest