Cambridge IGCSE

Chuyên luyện thi IELTS/SAT → AP / IB / A-levels

8020 ENGLISH

Cambridge IGCSE Chemistry

Giáo trình luyện thi chuyên sâu

Song ngữ Anh–Việt

8020 ENGLISH

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Lời mở đầu · Foreword

Cuốn sách này thuộc bộ giáo trình luyện thi chương trình quốc tế của **8020 English (8020 Education)** — trung tâm luyện thi trọng điểm **IELTS · SAT · AP · IB · A-level · IGCSE** và săn học bổng du học. Toàn bộ nội dung được biên soạn bởi đội ngũ **Giáo sư · Tiến sĩ · Thạc sĩ** tốt nghiệp các trường top đầu thế giới, bám sát khung chương trình chính thức, trình bày đầy đủ lý thuyết, ví dụ mẫu, hình minh hoạ và hệ thống bài tập có lời giải chi tiết.

This book is part of the 8020 English international exam-prep series: complete English theory with Vietnamese explanations, worked examples, illustrations and fully-solved practice, aligned to the official framework.

Thành tích 8020 English

9.0 IELTS cao nhất	**1570** SAT cao nhất
5/5 AP — điểm tuyệt đối	**90/100** IB Diploma
100% GV $\geq$ 8.0 IELTS / 1500 SAT	**CMU** Tiến sĩ ĐH #1 Hoa Kỳ về CS

Đội ngũ tiêu biểu: Thầy Châu Cát Tường (Academic Head, ThS Western Sydney, top 1% IELTS 8.5) · TS Nguyễn Anh Huy (Carnegie Mellon, cựu kỹ sư Amazon) · TS Nguyễn Phước Trường (Toán, ĐH Klagenfurt) · cùng đội ngũ giảng viên SAT 1500–1600, IELTS 8.0–8.5.

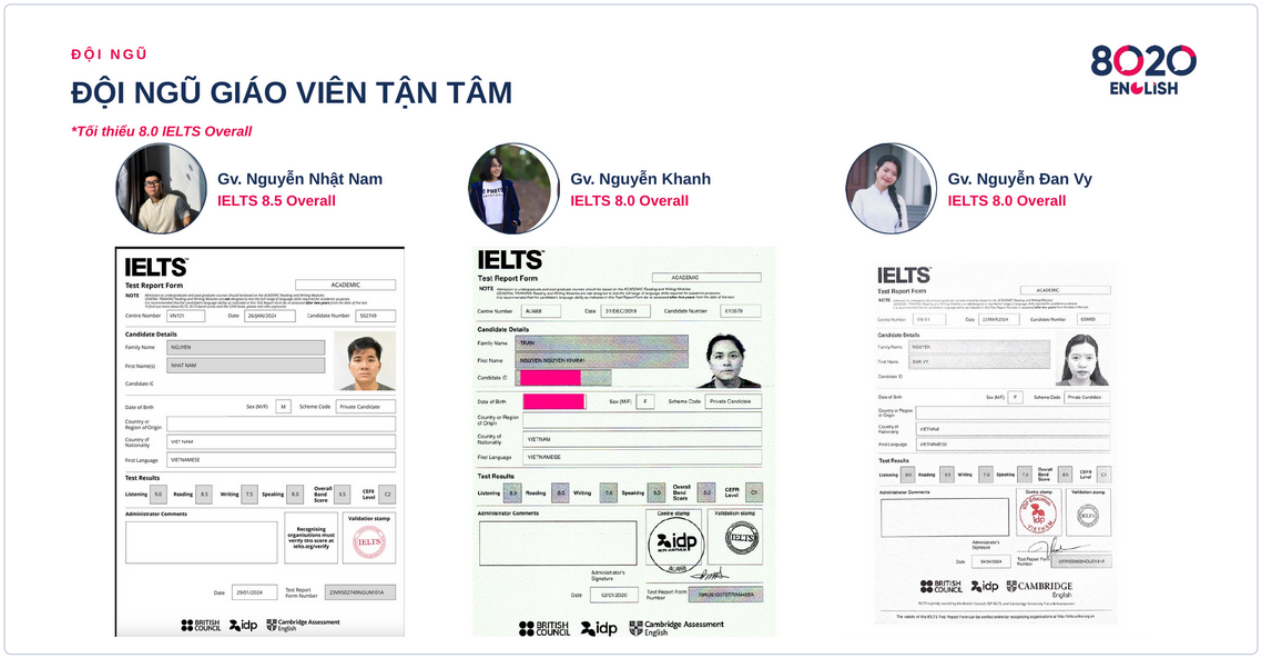
Kết quả học viên — điểm thi thật: IELTS 8.0–9.0 · SAT 1550 / 1570 / 1590 · AP 5/5 (Calculus BC, Microeconomics) · IB 90/100 (Economics) · Duolingo 110 · PTE 90 · TOEFL 120. **Bảng vàng SAT:** Khánh Đăng 1510 · Thảo Nguyên 1520 · Tâm Anh 1530.

"Cuối cùng đã đậu vào trường top như mong muốn." — Phan Thị Thanh Hằng, IELTS Overall 8.5.

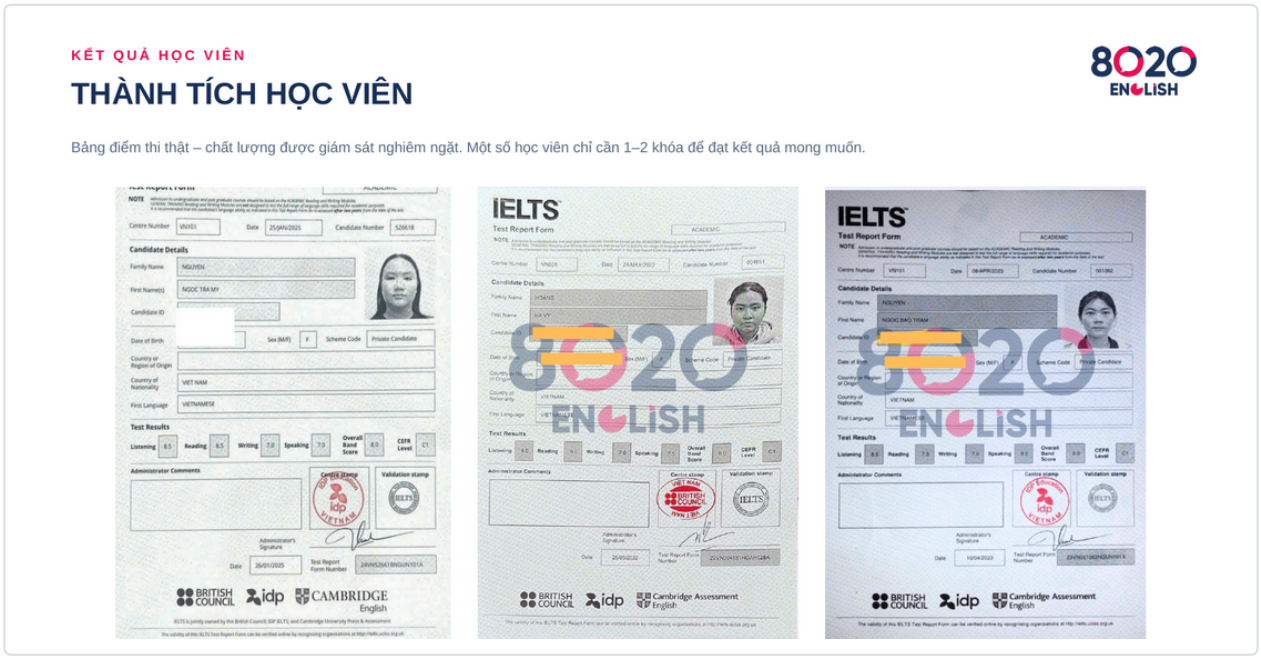
Cách dùng sách hiệu quả: mỗi Unit gồm (1) **Lý thuyết trọng tâm** tiếng Anh kèm **giải thích tiếng Việt**; (2) **Ví dụ mẫu** có lời giải; (3) **Hệ thống bài tập** kèm **lời giải chi tiết**. Hãy tự làm bài trước khi xem lời giải để đạt hiệu quả tối đa.

THÀNH TÍCH THỰC TẾ · 8020 ENGLISH

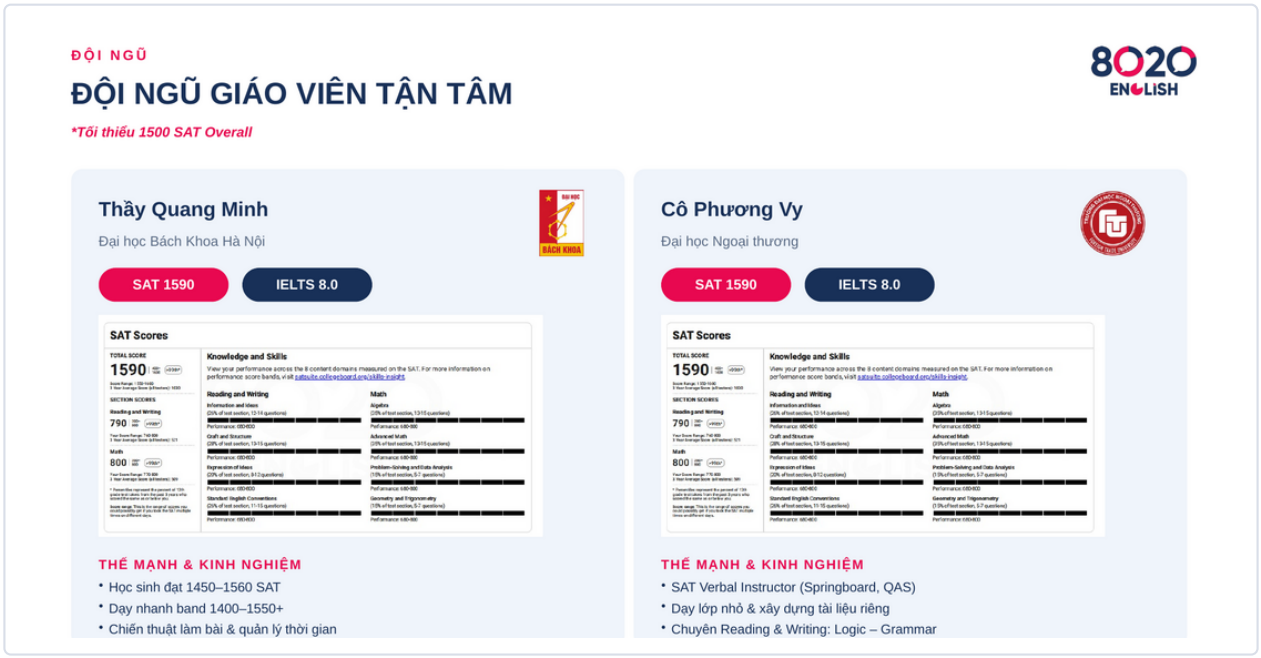
Điểm thi thật · Bằng & bảng điểm thật của giảng viên và học viên 8020 English — **Điểm thật · Thầy thật · Kết quả thật**



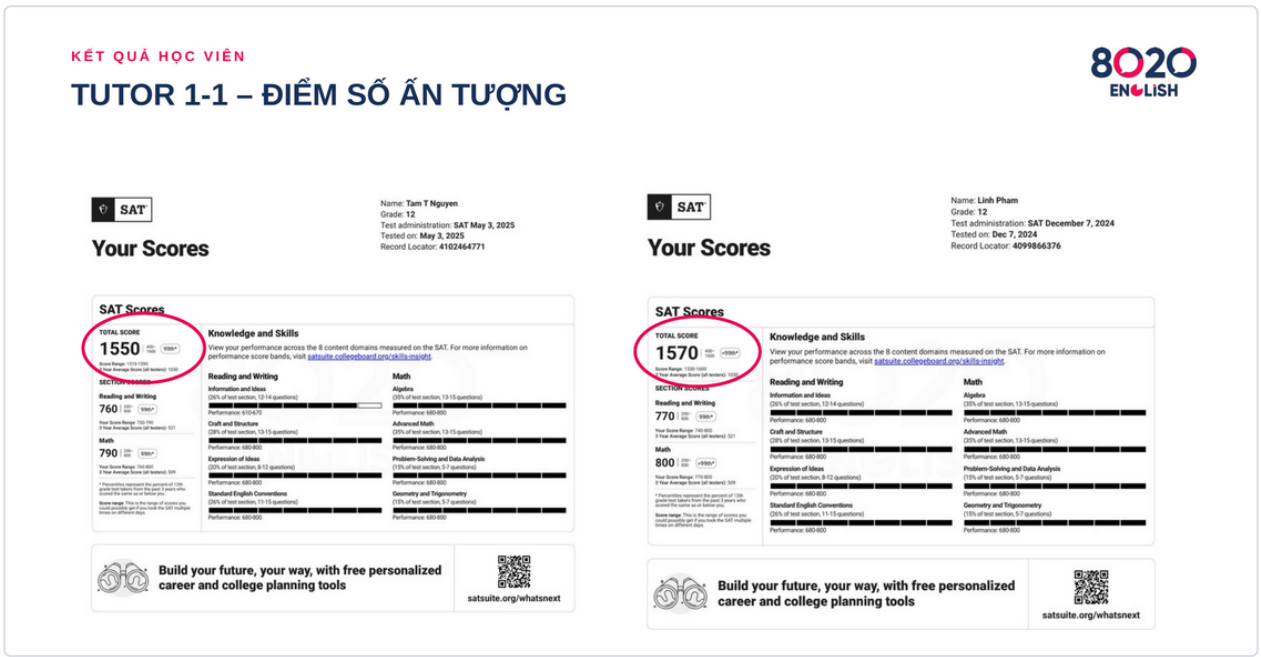
Giảng viên 8020 — IELTS 8.5 & 8.0 Overall (British Council · IDP · Cambridge)



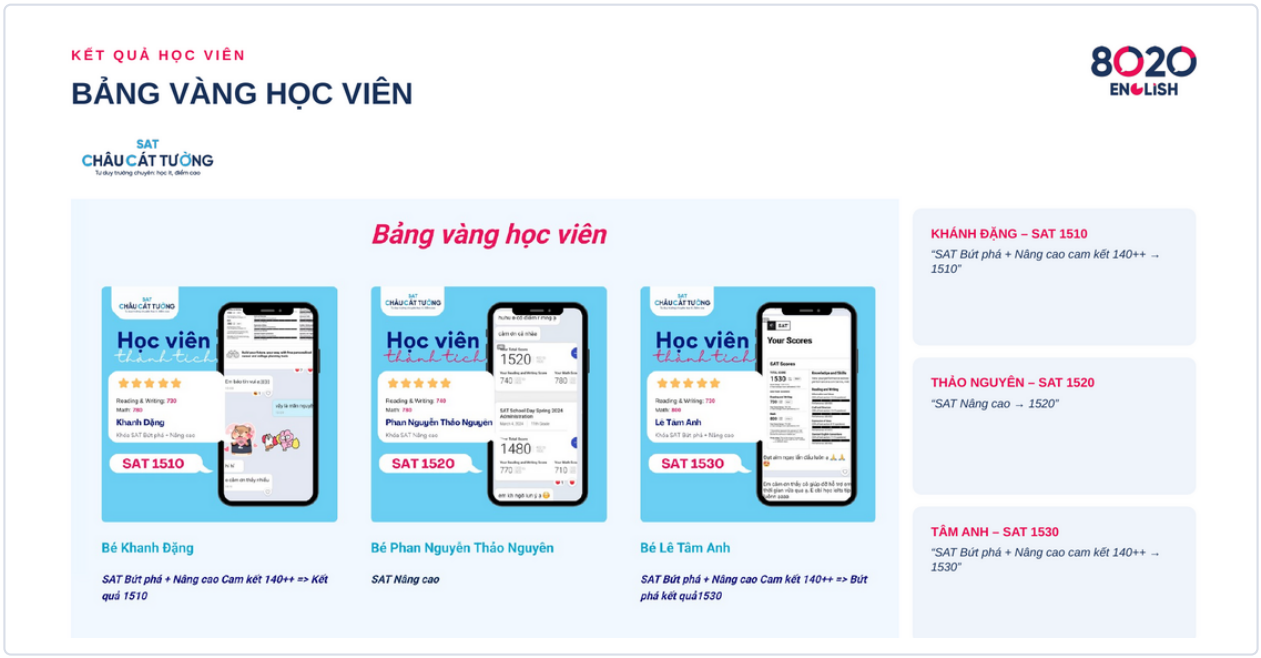
Học viên 8020 — IELTS 8.0 Overall (bảng điểm thật)



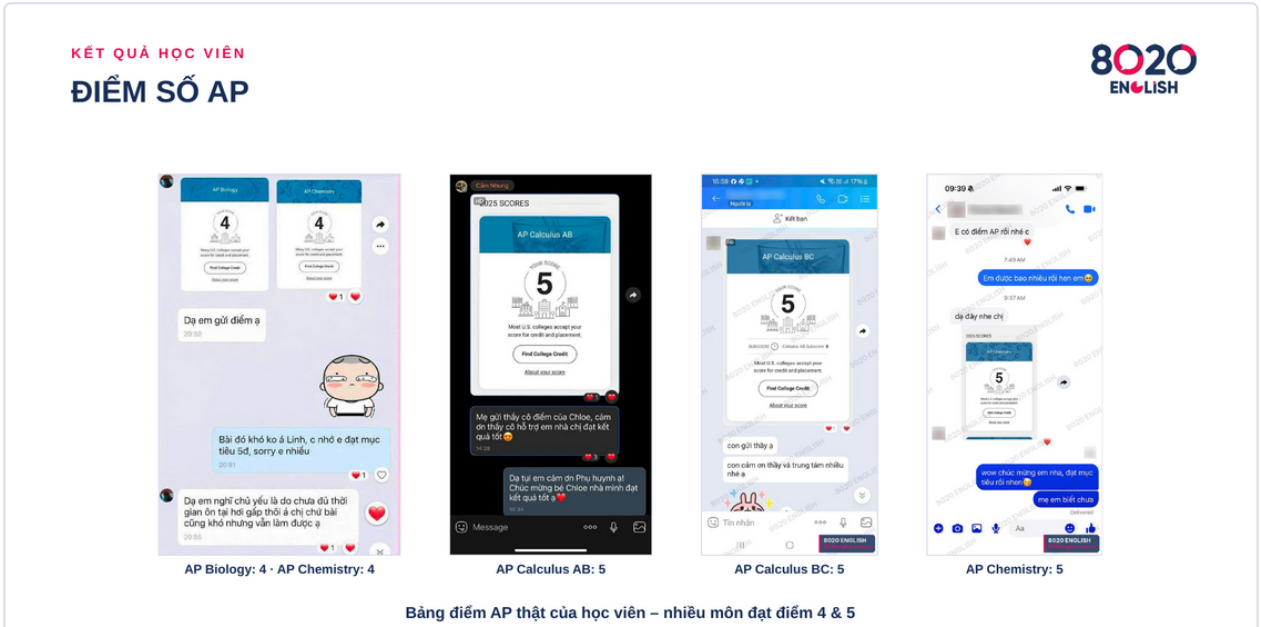
Giảng viên 8020 — SAT 1590 (ĐH Bách Khoa Hà Nội & ĐH Ngoại thương)



Học viên 8020 — SAT 1550 & 1570 (College Board)



Bảng vàng SAT — Học viên đạt 1510 · 1520 · 1530



Điểm AP thật — Calculus AB/BC 5/5 · Biology & Chemistry 4–5 (College Board)

Mục lục · Contents

States of Matter

Mục tiêu Unit: Thuyết động học phân tử (kinetic particle theory), ba trạng thái vật chất, sự chuyển thể (nóng chảy/sôi/ngưng tụ/đông đặc/thăng hoa), phân biệt sự bay hơi (evaporation) và sự sôi (boiling), khuếch tán (diffusion, định luật Graham), định luật Boyle và định luật Charles cho chất khí, và chuyển động Brown (Brownian motion) như bằng chứng thực nghiệm cho thuyết động học phân tử.

1.1 The kinetic particle theory

All matter is made of tiny particles (atoms, molecules or ions) that are in constant motion. The **kinetic particle theory** explains the observable properties of solids, liquids and gases in terms of the arrangement, spacing, movement and energy of these particles. The particles themselves do not change when a substance changes state — only their arrangement, spacing and energy change.

Key assumptions of the kinetic particle theory:

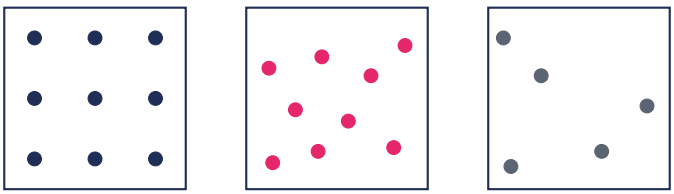
- All matter is made up of very small particles (atoms, molecules or ions).
- These particles are in constant motion — vibrating in solids, or moving from place to place in liquids and gases.
- The higher the temperature, the greater the average kinetic energy (and hence average speed) of the particles.
- There are forces of attraction between particles; these forces are strongest in solids, weaker in liquids, and (for most practical purposes) negligible in gases except during collisions.
- Particles collide with each other and with the walls of their container; in gases these collisions are responsible for gas pressure.

Khái niệm cốt lõi

Solid: particles fixed in an ordered, tightly-packed lattice, touching their neighbours, vibrating about fixed positions but not moving from place to place ⇒ fixed shape and fixed volume, cannot be compressed, high density.

Liquid: particles close together (only slightly further apart than in a solid) but randomly arranged, with enough energy to slide past one another ⇒ fixed volume but no fixed shape (takes the shape of its container), only very slightly compressible.

Gas: particles far apart (typically hundreds of times further apart than in a solid or liquid), moving rapidly and randomly in all directions, colliding with each other and with the walls of their container ⇒ no fixed shape or volume, easily compressed, very low density, completely fills any container.



Particle diagrams: a solid has an ordered, tightly-packed arrangement; a liquid is close-packed but disordered; a gas has widely-spaced, disordered particles.

VN **GIẢI THÍCH TIẾNG VIỆT**

Thuyết động học phân tử: **chất rắn** có hạt sắp xếp cố định, chạm sát nhau, chỉ rung tại chỗ (hình dạng & thể tích cố định, không nén được); **chất lỏng** có hạt gần nhau nhưng trượt qua lại được (thể tích cố định, hình dạng theo bình chứa); **chất khí** có hạt xa nhau, chuyển động nhanh và hỗn loạn (không có hình dạng/thể tích cố định, dễ nén, khối lượng riêng rất nhỏ). Bản thân các hạt không thay đổi khi chuyển thể — chỉ có cách sắp xếp, khoảng cách và năng lượng của chúng thay đổi.

1.1.1 Explaining macroscopic properties from the particle model

Every observable bulk property of a solid, liquid or gas can be traced back to the arrangement, spacing and motion of its particles.

- **Shape:** fixed only in a solid, where strong forces of attraction lock particles into an ordered lattice; particles in a liquid or gas are free to move, so the substance instead takes the shape of whatever container it is placed in.
- **Volume:** fixed in a solid and a liquid, because their particles are already touching (or almost touching) and cannot easily be pushed any closer together; a gas has no fixed volume because it expands to fill whatever container is available.
- **Density:** high in solids and liquids (mass packed into a small volume, particles touching), but very low in gases (the same number of particles is spread over a much larger volume, mostly empty space).
- **Compressibility:** solids and liquids are (for practical purposes) incompressible, since there is almost no space left between their particles to remove; a gas is easily compressed because there is a great deal of empty space between its widely-spaced particles.
- **Flow:** solids do not flow, because particles cannot move from place to place, only vibrate; liquids and gases both flow, because their particles are free to move past one another and slide/stream around obstacles.

VN **GIẢI THÍCH TIẾNG VIỆT**

Mọi tính chất quan sát được (hình dạng, thể tích, khối lượng riêng, khả năng nén, khả năng chảy) đều được giải thích trực tiếp từ mô hình hạt: **hình dạng** cố định chỉ khi hạt bị khoá chặt trong mạng tinh thể (rắn); **thể tích** cố định khi hạt đã chạm sát nhau (rắn, lỏng); **khối lượng riêng** lớn khi hạt xếp khít (rắn, lỏng), rất nhỏ khi hạt xa nhau (khí); **khả năng nén** chỉ đáng kể khi còn nhiều khoảng trống giữa các hạt (khí); **khả năng chảy** có được khi hạt tự do di chuyển qua lại (lỏng, khí) nhưng không có ở chất rắn (hạt chỉ rung tại chỗ).

1.1.2 Comparing solids, liquids and gases

Property	Solid	Liquid	Gas
Arrangement of particles	regular, ordered	irregular, close	irregular, far apart
Particle spacing	very close (touching)	close	very large
Particle energy	lowest	intermediate	highest
Particle movement	vibrate about fixed points	move/slide past each other	move freely, rapidly, randomly
Compressibility	none	almost none	easily compressed
Shape	fixed	takes shape of container	fills container completely
Volume	fixed	fixed	not fixed (fills container)
Density	high	high (usually slightly lower)	very low

VN **GIẢI THÍCH TIẾNG VIỆT**

Bảng so sánh trên là công cụ ôn tập nhanh: chất rắn có mọi thứ "cố định" (hình dạng, thể tích, vị trí hạt); chất khí gần như không có gì cố định (hạt tự do bay khắp mọi hướng); chất lỏng nằm ở giữa — thể tích cố định nhưng hình dạng thì không.

1.1.3 Interconverting the three states

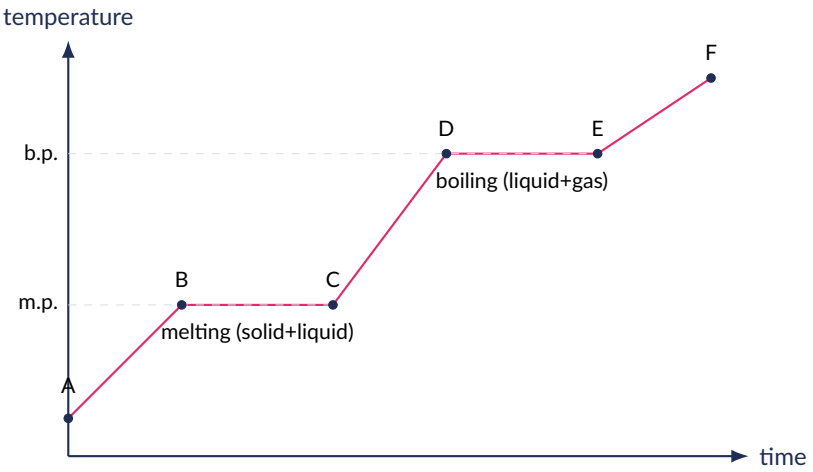
Change of state	Direction	Everyday example
Melting	solid → liquid	ice cube melting into water
Boiling/evaporation	liquid → gas	water boiling in a kettle; a puddle drying up
Condensation	gas → liquid	steam condensing on a cold mirror or window
Freezing	liquid → solid	water freezing into ice in a freezer
Sublimation	solid → gas (directly)	solid CO_2 ("dry ice"), iodine crystals, ammonium chloride

VN **GIẢI THÍCH TIẾNG VIỆT**

Sáu quá trình chuyển thể: nóng chảy (rắn→lỏng), sôi/bay hơi (lỏng→khí), ngưng tụ (khí→lỏng), đông đặc (lỏng→rắn), và thăng hoa (rắn→khí trực tiếp, không qua lỏng — ví dụ: đá khô CO_2, tinh thể iot, amoni clorua). Đây đều là biến đổi **vật lý**, không tạo ra chất mới và có thể đảo ngược.

1.2 Changes of state and energy

Melting (solid → liquid), boiling/evaporation (liquid → gas), condensation (gas → liquid), freezing (liquid → solid) and sublimation (solid → gas directly, with no liquid stage — e.g. iodine, solid carbon dioxide, ammonium chloride) are all changes of *physical* state: no new substance is formed, and the change can be reversed simply by heating or cooling. During melting or boiling, the temperature stays constant even while heating continues: the energy supplied is used entirely to weaken or overcome the forces of attraction between particles, allowing them to move further apart or move past one another, rather than to increase their average kinetic energy.

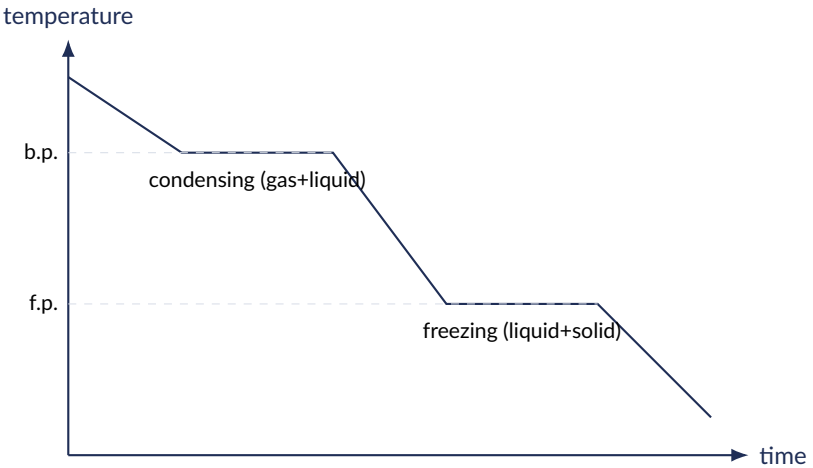


Heating curve of a pure solid (points A–F): the flat plateaus BC and DE occur because the supplied energy breaks intermolecular/interparticle forces of attraction, not because the average kinetic energy of the particles increases.

Ví dụ mẫu · Interpreting a heating curve

Using the heating curve above, describe what is happening to the particles of the substance, and to its temperature, in each of the regions AB, BC, CD, DE and EF.

AB: the substance is entirely solid; heat energy increases the particles' average kinetic energy, so they vibrate more vigorously about their fixed positions and the temperature rises steadily.
BC: the substance is melting — solid and liquid are present together at the melting point. All the heat energy supplied is used to overcome the forces of attraction holding particles in the solid lattice, freeing them to move past one another; average kinetic energy (and temperature) does not change, so the graph is flat.
CD: the substance is entirely liquid; heat energy again increases the particles' average kinetic energy, so they move faster and the temperature rises steadily.
DE: the substance is boiling — liquid and gas are present together at the boiling point. All the heat energy supplied is used to overcome the remaining forces of attraction, separating particles completely so they can move independently as a gas; temperature stays constant.
EF: the substance is entirely gas; heat energy increases the particles' average kinetic energy still further, so they move faster and the temperature continues to rise.



Cooling curve of the same pure substance: the plateaus occur at exactly the same temperatures as on the heating curve (condensation happens at the boiling point; freezing happens at the melting point), because energy must now be *removed* to allow particles to come closer together and slow down, rather than the temperature falling.

A **pure** substance melts and boils at one sharp, fixed temperature (at a given pressure). A **mixture** (or impure sample) melts and boils over a **range** of temperatures, and this range usually lies below the melting point and above the boiling point of the pure substance — this is why melting-point testing is a common way of checking the purity of a solid.

VN **GIẢI THÍCH TIẾNG VIỆT**

Trong đồ thị đun nóng/làm lạnh, đoạn nằm ngang (plateau) xảy ra đúng tại điểm nóng chảy hoặc điểm sôi. Ở đoạn này, năng lượng cấp vào (hoặc lấy ra) dùng để phá vỡ (hoặc hình thành lại) lực hút giữa các hạt, chứ không làm thay đổi nhiệt độ. Chất **tinh khiết** nóng chảy/sôi ở một nhiệt độ cố định; chất **hỗn hợp/không tinh khiết** nóng chảy/sôi trong một **khoảng** nhiệt độ — đây là cách kiểm tra độ tinh khiết đơn giản trong phòng thí nghiệm.

1.3 Evaporation and boiling

Evaporation is the escape of particles from the free surface of a liquid into the gas state, and — unlike boiling — it can happen at *any* temperature, even one far below the liquid's boiling point. Not every particle in a liquid has the same kinetic energy: at any instant there is a wide spread of energies among the particles, some moving quite slowly and others moving very fast. A particle can only escape as vapour if it is at (or very close to) the surface, moving outward, and happens to have enough kinetic energy at that moment to overcome the attractive forces pulling it back into the liquid. Only a small fraction of surface particles satisfy all three conditions simultaneously, so evaporation is normally a much slower process than boiling.

Các yếu tố ảnh hưởng đến tốc độ bay hơi · Factors affecting the rate of evaporation

- **Higher temperature:** raises the average kinetic energy of the particles, so a larger proportion of them have enough energy to escape from the surface at any given moment.
- **Larger surface area:** exposes more particles to the surface at once (e.g. spreading a liquid into a thin film or a shallow, wide dish), so more particles have the opportunity to escape per second.
- **Air movement (draught/wind):** sweeps escaped vapour particles away from just above the surface before they can collide with the liquid and re-condense; this keeps the vapour concentration just above the surface low, maintaining a large concentration gradient and a high *net* rate of evaporation.
- **Low humidity (dry air):** means the surrounding air is far from saturated with vapour, so relatively few vapour particles are available to strike the surface and condense back into the liquid; net evaporation is therefore faster than in humid air, which is already close to saturated with vapour.

VN **GIẢI THÍCH TIẾNG VIỆT**

Bay hơi xảy ra ở **bất kỳ nhiệt độ nào**, chỉ tại **bề mặt** chất lỏng, vì luôn có một số hạt ở bề mặt có đủ động năng để thoát ra ngoài dù nhiệt độ chưa đạt điểm sôi. Bốn yếu tố làm tăng tốc độ bay hơi: **nhiệt độ cao hơn** (nhiều hạt đủ năng lượng thoát ra hơn), **diện tích bề mặt lớn hơn** (nhiều hạt ở bề mặt có cơ hội thoát ra hơn), **gió/luồng không khí** (cuốn hơi thoát ra đi, giữ nồng độ hơi ngay trên bề mặt luôn thấp), và **độ ẩm thấp** (không khí chưa bão hoà hơi nước nên ít hơi ngưng tụ trở lại).

Ví dụ mẫu · Reasoning about evaporation rate

A wet towel hung outside on a hot, breezy day with low humidity dries completely in under an hour. The same wet towel, hung indoors on a cool, still, humid day, takes most of a day to dry. Explain this difference using kinetic particle theory.

Temperature: the hot day gives the water particles more kinetic energy on average, so a much larger fraction have enough energy to escape from the towel's surface at any instant.
Air movement: the breeze continually carries newly-evaporated water vapour away from the towel's surface, so the air right next to the towel never becomes saturated, keeping the net (outward) evaporation rate high; on a still day, vapour accumulates just above the surface and re-condenses onto the towel almost as fast as it evaporates.
Humidity: dry outdoor air can absorb far more water vapour before becoming saturated than humid indoor air, which is already close to saturated, so more net evaporation can occur into the drier air.
All three factors point the same way, so the towel on the hot, breezy, dry day evaporates its water very much faster.

Evaporation is a cooling process. Because only the most energetic particles escape from the surface, the particles left behind have, on average, *lower* kinetic energy than before — so the average kinetic energy, and therefore the temperature, of the remaining liquid falls. This is why sweat evaporating from skin has a cooling effect on the body, and why a volatile liquid such as ethanol or propanone (acetone) feels distinctly cold as it evaporates from the hand.

VN **GIẢI THÍCH TIẾNG VIỆT**
Vì chỉ những hạt có động năng cao nhất mới thoát ra được, năng lượng trung bình (và do đó nhiệt độ) của phần chất lỏng còn lại giảm xuống — đây là lý do mồ hôi bay hơi giúp làm mát cơ thể, và tại sao cồn hay axeton bay hơi tạo cảm giác lạnh trên da.

Boiling point and external pressure. A liquid boils when bubbles of vapour can form and grow throughout the whole liquid, not just escape from its surface — this happens once the liquid's vapour pressure becomes equal to the external (atmospheric) pressure pushing down on it. Reducing the external pressure (for example, at high altitude, where atmospheric pressure is lower than at sea level) means a lower vapour pressure — and therefore a *lower* temperature — is enough for boiling to begin. This is why water boils at a noticeably lower temperature on a high mountain than at sea level.

VN **GIẢI THÍCH TIẾNG VIỆT**
Chất lỏng sôi khi áp suất hơi của nó bằng áp suất khí quyển bên ngoài, cho phép bọt hơi hình thành khắp lòng chất lỏng chứ không chỉ ở bề mặt. Ở nơi có áp suất khí quyển thấp hơn (như trên núi cao), chỉ cần áp suất hơi thấp hơn (tức nhiệt độ thấp hơn) là chất lỏng đã sôi — vì vậy nước sôi ở nhiệt độ thấp hơn 100 °C trên núi cao so với ở mực nước biển.

(!) Lỗi thường gặp: Do not confuse **evaporation** (occurs at any temperature, only at the liquid's free surface, is a slow process) with **boiling** (occurs throughout the whole liquid at one fixed temperature — the boiling point — with bubbles of vapour forming inside the liquid itself, not just at the surface).

1.4 Diffusion

Diffusion is the net movement of particles from a region of higher concentration to a region of lower concentration, as a result of their own random motion — no stirring or outside force is needed. It occurs fastest in gases (particles move fastest and are furthest apart), much more slowly in liquids, and is negligible in solids (particles cannot move from place to place). Diffusion is faster at higher temperature, because particles have more kinetic energy and move faster on average; and, at a given temperature, diffusion is faster for particles of lower relative molecular mass M_r, because — since all particles at the same temperature have the same average kinetic energy — lighter particles must move faster to have that same kinetic energy ($E_k = \frac{1}{2}mv^2$).

Graham's Law of diffusion: at a fixed temperature, the rate of diffusion of a gas is inversely proportional to the square root of its relative molecular mass:

$$\text{rate} \propto \frac{1}{\sqrt{M_r}} \qquad \Longrightarrow \qquad \frac{\text{rate}_1}{\text{rate}_2} = \sqrt{\frac{M_r(2)}{M_r(1)}}.$$

Since, for a fixed distance, time taken is inversely proportional to rate, $\dfrac{\text{time}_1}{\text{time}_2} = \sqrt{\dfrac{M_r(1)}{M_r(2)}}$.

Ví dụ mẫu · Diffusion rates (Supplement)

Ammonia gas (NH_3, $M_r = 17$) and hydrogen chloride gas (HCl, $M_r = 36.5$) are released simultaneously from opposite ends of a long glass tube. A white ring of ammonium chloride ($NH_3 + HCl -> NH_4Cl$) forms closer to the HCl end. Estimate how many times faster NH_3 diffuses than HCl.

$$\frac{\text{rate}(NH_3)}{\text{rate}(HCl)} = \sqrt{\frac{M_r(HCl)}{M_r(NH_3)}} = \sqrt{\frac{36.5}{17}} = \sqrt{2.15} \approx 1.46.$$

So NH_3 travels about $1.46\times$ as far as HCl in the same time — consistent with the ring forming nearer the HCl end (the slower gas has travelled a shorter distance).

Ví dụ mẫu · Diffusion rates: carbon dioxide and helium (Supplement)

Carbon dioxide gas (CO_2, $M_r = 12 + 2(16) = 44$) and helium gas (He, $M_r = 4$) are released at the same time from opposite ends of a diffusion tube. Calculate the ratio of the distance travelled by helium to the distance travelled by carbon dioxide in the same time.

$$\frac{\text{rate(He)}}{\text{rate}(CO_2)} = \sqrt{\frac{M_r(CO_2)}{M_r(He)}} = \sqrt{\frac{44}{4}} = \sqrt{11} \approx 3.32.$$

Helium travels about **3.3 times** as far as carbon dioxide in the same time — its particles are eleven times lighter, so (having the same average kinetic energy at the same temperature) they move considerably faster.

Ví dụ mẫu · Diffusion rates: sulfur dioxide and oxygen (Supplement)

Sulfur dioxide gas (SO_2, $M_r = 32 + 2(16) = 64$) and oxygen gas (O_2, $M_r = 32$) are released at the same time from opposite ends of an identical diffusion tube. Calculate the ratio of the rate of diffusion of oxygen to that of sulfur dioxide.

$$\frac{\text{rate}(O_2)}{\text{rate}(SO_2)} = \sqrt{\frac{M_r(SO_2)}{M_r(O_2)}} = \sqrt{\frac{64}{32}} = \sqrt{2} \approx 1.41.$$

Oxygen diffuses about **1.4 times** as fast as sulfur dioxide, since its relative molecular mass is only half that of sulfur dioxide.

Ví dụ mẫu · Finding an unknown M_r from a diffusion ratio

Gas X is found to diffuse twice as fast as sulfur dioxide, SO_2 ($M_r = 32 + 2(16) = 64$). Calculate the relative molecular mass of gas X.

$$\frac{\text{rate(X)}}{\text{rate}(SO_2)} = 2 = \sqrt{\frac{64}{M_r(X)}} \implies 4 = \frac{64}{M_r(X)} \implies M_r(X) = \frac{64}{4} = 16.$$

$M_r(X) = 16$ — consistent with gas X being methane, CH_4 ($12 + 4 \times 1 = 16$).

Ví dụ mẫu · Comparing diffusion times

Under a given set of conditions, hydrogen gas (H_2, $M_r = 2$) takes 15 s to diffuse a certain distance along a tube. How long would water vapour (H_2O, $M_r = 18$) take to diffuse the same distance, at the same temperature?

Time is inversely proportional to rate, so time $\propto \sqrt{M_r}$:

$$\frac{t(H_2O)}{t(H_2)} = \sqrt{\frac{M_r(H_2O)}{M_r(H_2)}} = \sqrt{\frac{18}{2}} = \sqrt{9} = 3.$$

$t(H_2O) = 3 \times 15 = 45$ s.

VN **GIẢI THÍCH TIẾNG VIỆT**

Khuếch tán là hạt chuyển động ngẫu nhiên từ nơi **nồng độ cao** sang nơi **nồng độ thấp**, không cần khuấy trộn. Theo định luật Graham, tốc độ khuếch tán tỉ lệ nghịch với $\sqrt{M_r}$: khí có M_r càng nhỏ thì khuếch tán càng **nhanh**. Đây là lý do vòng khói trắng NH_4Cl luôn hình thành gần đầu ống chứa HCl (khí nặng hơn, khuếch tán chậm hơn) hơn là gần đầu chứa NH_3 (khí nhẹ hơn, khuếch tán nhanh hơn).

Factors affecting the rate of diffusion:

- **Temperature:** higher temperature ⇒ particles have more kinetic energy ⇒ faster diffusion.
- **Relative molecular mass, M_r:** lighter particles move faster at a given temperature ⇒ faster diffusion (Graham's Law).
- **Concentration gradient:** a bigger difference in concentration between two regions gives a faster net rate of diffusion.
- **State of matter:** diffusion is fastest in gases, much slower in liquids, and negligible in solids, because of the difference in particle spacing and freedom of movement.

(!) Lỗi thường gặp: A common error is to assume that *heavier* gas particles diffuse faster, or to mix up which gas belongs on which side of a diffusion ratio. Remember: at the same temperature, *all* gases have the same average kinetic energy ($E_k = \frac{1}{2}mv^2$), so *lighter* particles (smaller M_r) must move faster on average — and therefore diffuse faster and travel further in a given time. Before writing a ratio, always identify which gas has the *smaller* M_r: that is the faster (and, in a fixed-distance race, the "winning") gas.

1.5 Effect of temperature and pressure on gases

1.5.1 Temperature and gas pressure

For a fixed mass of gas in a sealed, rigid (fixed-volume) container, increasing the temperature increases the pressure. Kinetic particle theory explains this: heating raises the average kinetic energy of the gas particles, so they move faster; this increases both the **frequency** of collisions with the container walls (particles cross the container and hit the walls more often per second) and the **force** of each collision (faster particles transfer more momentum on impact) — both effects raise the pressure exerted on the walls.

VN **GIẢI THÍCH TIẾNG VIỆT**

Khi đun nóng một lượng khí cố định trong bình kín cứng (thể tích không đổi), động năng trung bình của các hạt tăng lên → hạt chuyển động nhanh hơn → va chạm với thành bình vừa **thường xuyên hơn** vừa **mạnh hơn** → áp suất khí tăng.

1.5.2 Pressure and volume of a gas (Supplement)

Compressing a fixed mass of gas at constant temperature into a smaller volume forces the same number of particles into a smaller space. The particles' average speed is unchanged (temperature is constant, so average kinetic energy is unchanged), but because the walls of the container are now closer together, particles collide with them far more *frequently* — so the pressure increases. Conversely, allowing the gas to expand into a larger volume at constant temperature reduces the frequency of wall collisions and lowers the pressure.

Boyle's Law (Supplement): for a fixed mass of gas at constant temperature, pressure and volume are inversely proportional — their product is constant:

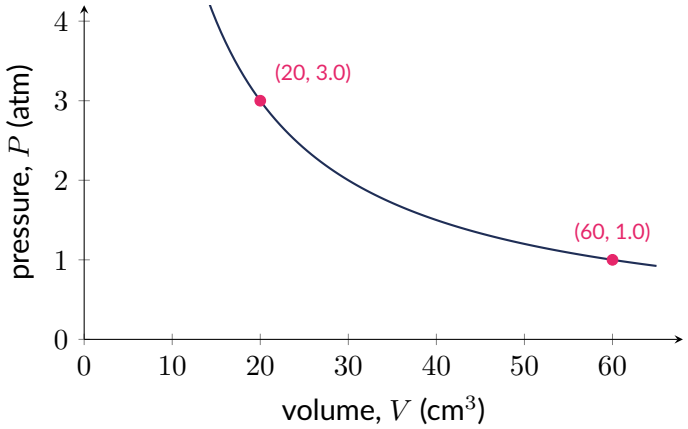
$$P_1V_1 = P_2V_2.$$

Ví dụ mẫu · Applying Boyle's Law (Supplement)

A gas syringe contains $60\,\text{cm}^3$ of air at a pressure of $1.0\,\text{atm}$. The plunger is pushed in, at constant temperature, until the volume is $20\,\text{cm}^3$. Calculate the new pressure of the gas.

$$P_1V_1 = P_2V_2 \implies (1.0)(60) = P_2(20) \implies P_2 = \frac{60}{20} = 3.0\,\text{atm}.$$

The volume was reduced to one-third of its original value, so (as expected from an inverse relationship) the pressure increased to three times its original value.



P against V for the gas syringe example: the curve is a hyperbola ($PV = 60 =$ constant), confirming the inverse relationship between pressure and volume at constant temperature.

VN **GIẢI THÍCH TIẾNG VIỆT**

Khi nén khí ở nhiệt độ không đổi, số hạt không đổi nhưng bị dồn vào thể tích nhỏ hơn → hạt va chạm với thành bình **thường xuyên hơn** (tốc độ trung bình không đổi vì nhiệt độ không đổi) → áp suất tăng. Định luật Boyle (mở rộng — Extended): $P_1V_1 = P_2V_2$ với khối lượng khí không đổi ở nhiệt độ không đổi.

(!) Lỗi thường gặp: When a sealed container of gas is heated, students sometimes say "the particles get bigger" or "more particles are created." Neither is true: the particles themselves do not change size or number. It is only their average *speed* (and hence the frequency and force of their collisions with the walls) that increases.

1.5.3 Volume and temperature of a gas (Supplement)

At *constant pressure*, heating a fixed mass of gas makes it expand. Kinetic particle theory explains this: heating raises the particles' average speed and hence the force of their collisions with the walls; for the pressure on the gas to stay the same (balanced, for example, against a constant external pressure on a freely-moving piston), the gas must occupy a larger volume, so that collisions with each unit of wall area become less frequent — exactly compensating for the greater force of each individual collision.

Charles' Law (Supplement): for a fixed mass of gas at constant pressure, volume is directly proportional to absolute (kelvin) temperature:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \qquad (T \text{ in kelvin, K}).$$

Temperature must always be converted from Celsius to kelvin before use: $T(\text{K}) = \theta(^\circ\text{C}) + 273$.

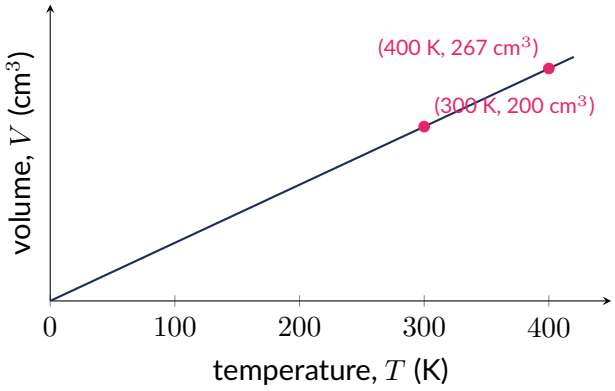
Ví dụ mẫu · Applying Charles' Law (Supplement)

A fixed mass of gas has a volume of $200\,\text{cm}^3$ at $27\,^\circ$C. It is heated, at constant pressure, to $127\,^\circ$C. Calculate its new volume.

First convert both temperatures to kelvin: $T_1 = 27 + 273 = 300\,\text{K}$; $T_2 = 127 + 273 = 400\,\text{K}$.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \implies \frac{200}{300} = \frac{V_2}{400} \implies V_2 = \frac{200 \times 400}{300} = 266.7\,\text{cm}^3 \text{ (3 s.f.)}.$$

The gas expands from $200\,\text{cm}^3$ to about $267\,\text{cm}^3$ as its kelvin temperature rises by a factor of $400/300$.



Charles' Law: at constant pressure, V is directly proportional to kelvin temperature T — a straight line through the origin of the V–T graph.

VN **GIẢI THÍCH TIẾNG VIỆT**

Định luật Charles: ở áp suất không đổi, thể tích khí tỉ lệ thuận với nhiệt độ tuyệt đối (Kelvin): $V_1/T_1 = V_2/T_2$. Luôn phải đổi từ độ C sang Kelvin trước khi tính: $T(\text{K}) = \theta(^\circ\text{C}) + 273$. Đồ thị V theo T (Kelvin) là một đường thẳng đi qua gốc toạ độ.

(!) Lỗi thường gặp: Both Charles' Law and the combined gas law require temperature in **kelvin**, never Celsius. A common mistake is substituting Celsius values directly into $V_1/T_1 = V_2/T_2$ (e.g., treating $0\,^\circ\text{C}$ as $T = 0$). Always convert first using $T(\text{K}) = \theta(^\circ\text{C}) + 273$ — forgetting this step, or converting incorrectly, is one of the most frequent sources of wrong answers in gas-law calculations.

1.5.4 Combining pressure, volume and temperature (Supplement)

Boyle's Law and Charles' Law can be combined into a single relationship that holds for a fixed mass of gas whenever pressure, volume *and* temperature all change together:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \qquad (T \text{ in kelvin, K}).$$

Setting $T_1 = T_2$ recovers Boyle's Law; setting $P_1 = P_2$ recovers Charles' Law.

Ví dụ mẫu · Combined gas law (Supplement)

A fixed mass of gas has a volume of $600\,\text{cm}^3$ at a pressure of $100\,\text{kPa}$ and a temperature of $27\,^\circ\text{C}$. It is compressed and heated until its pressure is $200\,\text{kPa}$ and its temperature is $87\,^\circ\text{C}$. Calculate its new volume.

$T_1 = 27 + 273 = 300\,\text{K}$; $T_2 = 87 + 273 = 360\,\text{K}$.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \implies \frac{(100)(600)}{300} = \frac{(200)V_2}{360} \implies V_2 = \frac{100 \times 600 \times 360}{300 \times 200} = 360\,\text{cm}^3.$$

Check by separate factors: doubling the pressure ($100 \to 200\,\text{kPa}$) alone would halve the volume to $300\,\text{cm}^3$; increasing T from 300 K to 360 K alone would multiply the volume by

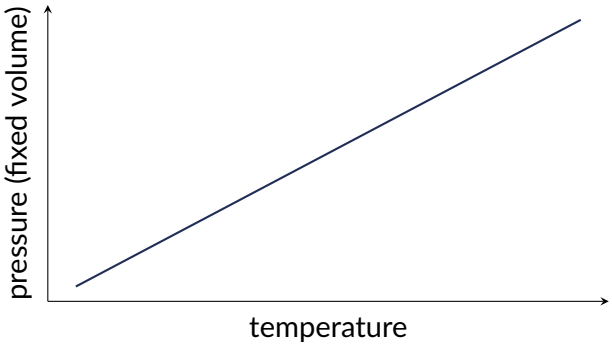
$360/300 = 1.2$, giving $300 \times 1.2 = 360\,\text{cm}^3$ — consistent.

VN GIẢI THÍCH TIẾNG VIỆT

Kết hợp định luật Boyle và Charles: $P_1V_1/T_1 = P_2V_2/T_2$ (nhiệt độ luôn tính bằng Kelvin) áp dụng khi cả áp suất, thể tích và nhiệt độ đều thay đổi đồng thời với một lượng khí cố định. Nếu T không đổi thì trở về định luật Boyle; nếu P không đổi thì trở về định luật Charles.

1.5.5 Pressure and temperature — a qualitative graph

For a fixed mass of gas held at constant volume, pressure rises steadily as temperature rises, because of the increased frequency and force of particle collisions with the container walls described above. No numerical law connecting P and T is required at this level — only the qualitative trend and its kinetic-theory explanation.



Pressure of a fixed mass of gas at constant volume increases steadily as temperature increases — more frequent, more forceful collisions with the container walls.

VN GIẢI THÍCH TIẾNG VIỆT

Ở thể tích không đổi, áp suất khí tăng đều khi nhiệt độ tăng, do va chạm của hạt lên thành bình vừa thường xuyên hơn vừa mạnh hơn. Ở cấp độ IGCSE, mối quan hệ áp suất–nhiệt độ này chỉ cần hiểu về mặt định tính (không có công thức số bắt buộc), khác với định luật Boyle và Charles vốn được tính toán định lượng.

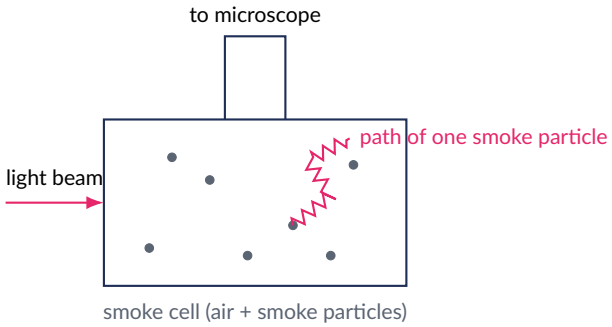
1.5.6 Brownian motion (Supplement)

In 1827, the botanist Robert Brown observed pollen grains suspended in water under a microscope and noticed that they moved continuously in an erratic, random, zig-zag path — even though the pollen grains themselves had no means of self-propulsion. This phenomenon, **Brownian motion**, provided important evidence for the kinetic particle theory: the pollen grains are constantly being bombarded, unevenly and from random directions, by fast-moving, invisible water molecules, and each individual collision knocks the much larger, heavier grain slightly off its path.

Bằng chứng thực nghiệm · The smoke cell experiment (Supplement)

A modern version of the same demonstration uses smoke trapped in a glass cell, illuminated from the side and viewed from above through a microscope. The tiny smoke particles appear as bright specks that dance about randomly rather than settling or moving in a straight line. This is because the (invisible) air molecules in the cell are moving extremely fast in random directions, and are constantly colliding with the (visible, but still very small) smoke particles from all sides — at any instant, slightly more collisions from one side than the other push a

smoke particle in an unpredictable new direction.



Smoke-cell apparatus: smoke particles, visible under the microscope, are knocked about randomly by invisible, fast-moving air molecules — the erratic zig-zag path is Brownian motion.

(Supplement) Brownian motion is evidence that: (1) matter is made of constantly moving particles; (2) particles of very different sizes exist together — large, visible smoke or pollen particles surrounded by tiny, invisible gas or liquid molecules; (3) the motion is random and becomes more vigorous at higher temperature (particles have more kinetic energy, so collisions are more frequent and more forceful).

VN **GIẢI THÍCH TIẾNG VIỆT**

Chuyển động Brown là bằng chứng thực nghiệm cho thuyết động học phân tử: các hạt phấn hoa (hoặc khói) tuy nhìn thấy được nhưng tự nó không thể di chuyển — chúng bị các phân tử khí/nước **vô hình, chuyển động rất nhanh** va chạm liên tục và ngẫu nhiên từ mọi phía, khiến hạt lớn hơn bị đẩy đi theo đường zig-zag không thể đoán trước. Nhiệt độ càng cao, chuyển động Brown càng mạnh (hạt khí có động năng lớn hơn).

Ví dụ mẫu · Explaining Brownian motion (Supplement)

The apparatus in the figure above is used to observe smoke particles in air at room temperature. Predict and explain what would be observed if the air inside the smoke cell were instead heated to a much higher temperature.

The zig-zag movement of the smoke particles would become noticeably **more vigorous** — the particles would appear to dart about faster and more erratically. Heating increases the average kinetic energy of the (invisible) air molecules, so they move faster; this increases both the *frequency* and the *force* of their random collisions with each smoke particle, producing larger, more frequent, unbalanced impulses that deflect the smoke particles more rapidly onto new paths.

1.6 Practical investigations of particle behaviour

1.6.1 The ammonia/hydrogen chloride diffusion tube

A classic demonstration of gaseous diffusion and Graham's Law uses a long, dry glass tube. A cotton-wool plug soaked in concentrated ammonia solution is placed in one end, and a second cotton-wool plug soaked in concentrated hydrochloric acid is placed in the other end, at the same instant. Both liquids release gas (NH_3 and HCl respectively), which diffuse towards each other along the tube. Where the two gases meet, they react to form a visible white ring of solid ammonium chloride smoke: $NH_3 + HCl -> NH_4Cl$.

The diffusion tube: because NH_3 ($M_r = 17$) diffuses about $1.46\times$ faster than HCl ($M_r = 36.5$), the white ring forms noticeably closer to the hydrochloric acid end of the tube than to the ammonia end.

1.6.2 Diffusion in liquids

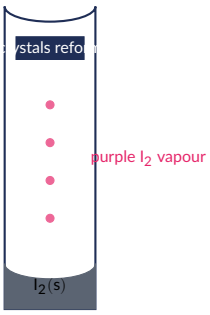
Diffusion also occurs in liquids, but far more slowly than in gases, because liquid particles are much closer together and are constantly obstructed by collisions with their many close neighbours. This can be shown by carefully lowering a single small crystal of potassium manganate(VII) ($KMnO_4$) into a beaker of still water, without stirring: a deep purple colour slowly spreads out from the crystal in all directions over many minutes (or hours), eventually colouring the whole beaker of water a pale purple, as MnO_4^- ions diffuse through the liquid. The much slower rate compared to gaseous diffusion is a direct consequence of particle spacing and the resulting frequency of collisions.

VN **GIẢI THÍCH TIẾNG VIỆT**

Thí nghiệm hạt tinh thể thuốc tím ($KMnO_4$) trong nước cho thấy khuếch tán trong chất lỏng diễn ra rất chậm so với chất khí (thí nghiệm ống NH_3/HCl), vì các hạt trong chất lỏng ở gần nhau hơn và va chạm với hàng xóm thường xuyên hơn, cản trở chuyển động tự do.

1.6.3 Sublimation of iodine

Solid iodine sublimes readily on gentle heating: purple iodine vapour forms directly from the grey-black solid without passing through a liquid stage, and re-forms as solid iodine crystals on any cooler surface it touches (such as the upper, unheated part of a test tube, or a cold watch-glass held above it) — a process called *deposition*, the reverse of sublimation.



Iodine sublimes on gentle heating (solid → purple vapour) and deposits again as solid crystals on a cooler surface (vapour → solid) — both changes with no liquid stage.

1.6.4 Ammonium chloride: a "sublimation" with a twist

When solid ammonium chloride is heated strongly in a test tube, white fumes appear near the hot region and a white solid re-forms further up the (cooler) tube, with no liquid ever seen — visually, this looks just like sublimation. In fact, ammonium chloride does not sublime as a single, unchanged substance: on strong heating it thermally decomposes into two separate gases,

$$NH_4Cl(s) -> NH_3(g) + HCl(g),$$

and as these two gases diffuse into the cooler part of the tube, they recombine to re-form solid ammonium chloride,

$$NH_3(g) + HCl(g) -> NH_4Cl(s).$$

The overall effect — solid disappearing at the hot end and solid reappearing further along, with no liquid stage — closely resembles true sublimation, which is why ammonium chloride is conventionally listed alongside iodine and solid carbon dioxide as a familiar sublimation example, even though the underlying process is a reversible thermal decomposition rather than a single substance changing state directly.

VN **GIẢI THÍCH TIẾNG VIỆT**

Khi đun nóng amoni clorua rắn, hiện tượng quan sát được (chất rắn biến mất ở đầu nóng, chất rắn xuất hiện trở lại ở đoạn ống lạnh hơn, không thấy giai đoạn lỏng) trông giống hệt sự thăng hoa. Nhưng về bản chất hoá học, đây là một phản ứng phân huỷ thuận nghịch: NH_4Cl phân huỷ thành hai khí NH_3 và HCl khi đun nóng, rồi hai khí này khuếch tán đến vùng lạnh hơn và kết hợp lại thành NH_4Cl rắn. Vì hiệu ứng quan sát được giống thăng hoa, NH_4Cl vẫn thường được liệt kê là một ví dụ thăng hoa quen thuộc cùng với iot và đá khô.

1.7 Exam-style practice

Bài tập luyện tập

Which state of matter has particles that vibrate about *fixed* positions but do not change places with neighbouring particles?

(A) Solid
(B) Liquid
(C) Gas
(D) Plasma

Lời giải chi tiết

In a solid, particles are held in a fixed lattice by strong forces of attraction and can only vibrate about a mean position. **(A)**.

Bài tập luyện tập

Solid carbon dioxide ("dry ice") turns directly into a gas at room temperature and pressure without forming a liquid. This process is called:

(A) Evaporation
(B) Sublimation
(C) Condensation
(D) Diffusion

Lời giải chi tiết

A direct solid-to-gas change (with no liquid stage) is **sublimation**. **(B)**.

Bài tập luyện tập

Neon gas (Ne, $M_r = 20$) and argon gas (Ar, $M_r = 40$) are released at the same time from two ends of a diffusion tube. Calculate the ratio of the distance travelled by neon to the distance travelled by argon in the same time.

Lời giải chi tiết

$\frac{\text{rate(Ne)}}{\text{rate(Ar)}} = \sqrt{\frac{M_r(\text{Ar})}{M_r(\text{Ne})}} = \sqrt{\frac{40}{20}} = \sqrt{2} \approx 1.41$. Neon travels about **1.4 times** as far as argon in the same time, since it has half the relative molecular mass and so, on average, moves faster at the same temperature.

Bài tập luyện tập

When a fixed mass of gas in a sealed rigid container is heated, its pressure increases. Using kinetic particle theory, which explanation is correct?

(A) The gas particles get bigger

(B) Particles move faster and collide with the walls more often and with greater force

(C) Particles diffuse out of the container

(D) The number of gas particles increases

Lời giải chi tiết

Heating increases the average kinetic energy of the particles, so they move faster; this raises both the *frequency* and the *force* of collisions with the container walls, increasing pressure. **(B)**.

Bài tập luyện tập

A student heats a solid until it is completely molten and records temperature every 30 seconds. Explain, in terms of particles and energy, why the temperature does not rise during melting even though heating continues.

Lời giải chi tiết

During melting, the solid and liquid states exist together. The heat energy supplied is used entirely to weaken/overcome the forces of attraction holding particles in the solid lattice, allowing them to move past one another, rather than increasing their average kinetic energy — so the thermometer reading (temperature) stays constant until melting is complete and all the particles have gained enough freedom to move as a liquid.

Bài tập luyện tập

(Supplement) A fixed mass of gas occupies $400\,\text{cm}^3$ at a pressure of 2.5 atm. Calculate the new pressure if it is compressed, at constant temperature, to $100\,\text{cm}^3$.

Lời giải chi tiết

$P_1V_1 = P_2V_2 \;\Rightarrow\; (2.5)(400) = P_2(100) \;\Rightarrow\; P_2 = \frac{1000}{100} = 10\,\text{atm}$.

Bài tập luyện tập

(Supplement) A gas has a pressure of $100\,\text{kPa}$ when it occupies $500\,\text{cm}^3$. What volume will it occupy, at the same temperature, if the pressure is reduced to $62.5\,\text{kPa}$?

Lời giải chi tiết

$P_1V_1 = P_2V_2 \Rightarrow (100)(500) = (62.5)V_2 \Rightarrow V_2 = \dfrac{50000}{62.5} = 800\,\text{cm}^3$.

Bài tập luyện tập

Oxygen gas (O_2, $M_r = 32$) and hydrogen gas (H_2, $M_r = 2$) are released simultaneously from identical pinholes into a vacuum. Calculate how many times faster hydrogen diffuses compared with oxygen.

Lời giải chi tiết

$\dfrac{\text{rate}(H_2)}{\text{rate}(O_2)} = \sqrt{\dfrac{32}{2}} = \sqrt{16} = 4$. Hydrogen diffuses **4 times** as fast as oxygen, since its particles have $\frac{1}{16}$ the mass but (at the same temperature) the same average kinetic energy, so they must move much faster.

Bài tập luyện tập

Gas W takes twice as long as methane, CH_4 ($M_r = 16$), to diffuse a fixed distance under the same conditions. Calculate the relative molecular mass of gas W.

Lời giải chi tiết

Time $\propto \sqrt{M_r}$, so $\dfrac{t(\text{W})}{t(CH_4)} = 2 = \sqrt{\dfrac{M_r(\text{W})}{16}} \Rightarrow 4 = \dfrac{M_r(\text{W})}{16} \Rightarrow M_r(\text{W}) = 64$. This is consistent with gas W being sulfur dioxide, SO_2 ($32 + 2 \times 16 = 64$).

Bài tập luyện tập

Explain, using the smoke-cell experiment, what causes the erratic (zig-zag) movement of the smoke particles seen under the microscope, and state what this observation provides evidence for.

Lời giải chi tiết

The smoke particles are constantly struck, randomly and unevenly from all directions, by fast-moving, invisible air molecules; an uneven number of collisions from one side at any instant knocks a smoke particle onto a new random path. This (Brownian motion) is direct evidence that matter is made of constantly, randomly moving particles that are far too small to see directly, and that these particles collide with larger visible particles.

Bài tập luyện tập

Why can gases be compressed far more easily than liquids or solids?

(A) Gas particles are smaller than liquid or solid particles

(B) There are large spaces between gas particles that can be reduced

(C) Gas particles have no mass

(D) Gas particles do not move

Lời giải chi tiết

Particles in a gas are very far apart, so there is a lot of empty space between them that can be reduced when the gas is squeezed into a smaller volume. In a liquid or solid, particles are already touching, so there is almost no space left to remove. **(B)**.

Bài tập luyện tập

Explain, in terms of particle spacing, why a gas has a much lower density than the same substance in its liquid state.

Lời giải chi tiết

Density $=$ mass $\div$ volume. The particles in a gas are spread out over a much larger volume than the same number (and mass) of particles in the liquid, so the same mass occupies far more space in the gas state — giving the gas a much lower density.

Bài tập luyện tập

Explain why the smell of perfume spreads across a room noticeably faster on a warm day than on a cold day.

Lời giải chi tiết

At a higher temperature, the perfume vapour particles (and the air particles around them) have more kinetic energy, so they move faster on average. Since diffusion is the net movement of particles due to their own random motion, faster-moving particles diffuse across the room more quickly.

Bài tập luyện tập

A pure substance is heated steadily from $20\,^{\circ}$C. Its temperature rises, then remains at $80\,^{\circ}$C for several minutes, then rises again, then remains at $150\,^{\circ}$C. State the melting point and boiling point of the substance, and explain why the temperature does not rise at $80\,^{\circ}$C even though heating continues.

Lời giải chi tiết

Melting point $=80\,^{\circ}$C; boiling point $=150\,^{\circ}$C. At $80\,^{\circ}$C, both solid and liquid are present together; the energy supplied is used to overcome the forces of attraction holding particles in the solid lattice (allowing them to move past each other as a liquid), not to raise their average kinetic energy — so the temperature stays constant until melting is complete.

Bài tập luyện tập

Explain, in terms of kinetic particle theory, why the pressure inside a sealed aerosol canister increases if it is left in direct sunlight on a hot day, and why manufacturers print warnings against exposing such canisters to heat.

Lời giải chi tiết

Heating increases the average kinetic energy of the gas particles inside the (fixed-volume) canister, so they move faster; this increases both the frequency and the force of their collisions with the inside walls of the canister, increasing the pressure. If the pressure rises enough, it can exceed the strength of the canister and cause it to burst or explode — hence the warning.

Bài tập luyện tập

Gas X has $M_r = 32$ and gas Y has $M_r = 64$, both at the same temperature. (a) Which gas's particles move faster on average, and why? (b) Calculate the ratio of the rate of diffusion of X to the rate of diffusion of Y.

Lời giải chi tiết

(a) Gas X moves faster on average. At the same temperature, both gases have the same average kinetic energy ($E_k = \frac{1}{2}mv^2$); since X's particles have a smaller mass, they must have a greater average speed to have the same kinetic energy.

(b) $\dfrac{\text{rate(X)}}{\text{rate(Y)}} = \sqrt{\dfrac{64}{32}} = \sqrt{2} \approx 1.41$. Gas X diffuses about **1.4 times** as fast as gas Y.

Bài tập luyện tập

Explain why a gas leak in a small closed room is usually detected (by smell) much sooner than the same size leak in a large open hall.

Lời giải chi tiết

Diffusion is the spreading of particles from a region of high concentration to a region of low concentration. In a small room, the same number of gas particles reach a much higher concentration (and travel a much shorter distance to reach a person's nose) than in a large hall, where the particles must diffuse much further and become far more diluted before being detected.

Bài tập luyện tập

(Supplement) A fixed mass of gas occupies $250\,\text{cm}^3$ at a pressure of $150\,\text{kPa}$. (a) Calculate its volume if the pressure is increased to $500\,\text{kPa}$ at constant temperature. (b) Explain, using kinetic particle theory, why the pressure increases when the same gas is compressed into a smaller volume at constant temperature.

Lời giải chi tiết

(a) $P_1V_1 = P_2V_2 \;\Rightarrow\; (150)(250) = (500)V_2 \;\Rightarrow\; V_2 = \dfrac{37500}{500} = 75\,\text{cm}^3$.

(b) The same number of gas particles are now confined to a smaller volume; their average speed is unchanged (temperature is constant), but the container walls are closer together, so particles collide with them far more frequently — increasing the pressure.

Bài tập luyện tập

Which statement correctly describes the arrangement of particles in a liquid?

(A) Fixed, regularly ordered, touching neighbours
(B) Close together, but randomly arranged, able to move past each other
(C) Far apart, moving randomly in all directions
(D) Fixed in position with large gaps between particles

Lời giải chi tiết

Liquid particles are close together (similar spacing to a solid) but not held in a fixed, ordered lattice — they are free to move past one another. **(B)**.

Bài tập luyện tập

A solid substance is found to melt gradually over the range $40\,^{\circ}$C to $55\,^{\circ}$C, rather than sharply at a single fixed temperature. What does this suggest about the substance?

(A) It is a pure element
(B) It is a pure compound
(C) It is a mixture or an impure sample
(D) It is a gas at room temperature

Lời giải chi tiết

A sharp, fixed melting point is characteristic of a pure substance. Melting over a range of temperatures indicates the sample contains a mixture of substances (or is an impure sample of one substance). **(C)**.

Bài tập luyện tập

State three differences between evaporation and boiling.

Lời giải chi tiết

(1) Evaporation happens only at the free surface of the liquid; boiling happens throughout the whole liquid, with bubbles of vapour forming inside it. (2) Evaporation can occur at any temperature below the boiling point; boiling occurs only at one fixed temperature (the boiling point). (3) Evaporation is a slow process; boiling is generally a much faster, more vigorous process once the boiling point is reached.

Bài tập luyện tập

Bromine vapour, Br_2 ($M_r = 2 \times 80 = 160$), and chlorine gas, Cl_2 ($M_r = 2 \times 35.5 = 71$), are released simultaneously from opposite ends of a diffusion tube. Calculate how many times faster chlorine gas diffuses compared with bromine vapour.

Lời giải chi tiết

$\dfrac{\text{rate}(Cl_2)}{\text{rate}(Br_2)} = \sqrt{\dfrac{160}{71}} = \sqrt{2.25} \approx 1.50$. Chlorine gas diffuses about **1.5 times** as fast as bromine vapour, because its particles have a lower relative molecular mass.

Bài tập luyện tập

(Supplement) State two pieces of evidence that Brownian motion provides in support of the kinetic particle theory.

Lời giải chi tiết

(1) It shows that matter is made of particles that are in constant, random motion (the visible smoke/pollen particles would not move erratically on their own). (2) It shows that these moving particles vary greatly in size — tiny, invisible molecules of gas or liquid are numerous and fast enough to visibly deflect much larger, visible particles through repeated random collisions.

Bài tập luyện tập

Naphthalene "mothballs" gradually disappear over several weeks when left in a wardrobe, without ever forming a visible liquid. This change of state is:

(A) Evaporation
(B) Melting
(C) Sublimation
(D) Condensation

Lời giải chi tiết

A direct solid-to-gas change, with no liquid stage, is **sublimation**. **(C)**.

Bài tập luyện tập

Four gases — hydrogen ($M_r = 2$), methane ($M_r = 16$), carbon dioxide ($M_r = 44$) and sulfur dioxide ($M_r = 64$) — are released simultaneously from the same point. Rank them in order from fastest to slowest rate of diffusion, and justify your ranking.

Lời giải chi tiết

Rate of diffusion is inversely proportional to $\sqrt{M_r}$, so the gas with the *smallest* M_r diffuses fastest. Ranking (fastest $\rightarrow$ slowest): hydrogen ($M_r = 2$) $>$ methane ($M_r = 16$) $>$ carbon dioxide ($M_r = 44$) $>$ sulfur dioxide ($M_r = 64$).

Bài tập luyện tập

(Supplement) A fixed mass of gas has a volume of $45\,\text{cm}^3$ at a pressure of $200\,\text{kPa}$. What was its original volume if its pressure was $90\,\text{kPa}$ at the same temperature?

Lời giải chi tiết

Let the original volume be V_1 at $P_1 = 90\,\text{kPa}$, and the final state be $P_2 = 200\,\text{kPa}$, $V_2 = 45\,\text{cm}^3$.

$$P_1V_1 = P_2V_2 \;\Rightarrow\; 90\,V_1 = 200 \times 45 = 9000 \;\Rightarrow\; V_1 = \frac{9000}{90} = 100\,\text{cm}^3.$$

Bài tập luyện tập

A rigid, sealed metal cylinder of gas is left on a table overnight and its temperature falls from $25\,^\circ\text{C}$ to $15\,^\circ\text{C}$. What happens to the pressure inside the cylinder, and why?

Lời giải chi tiết

The pressure **decreases**. Cooling reduces the average kinetic energy of the gas particles, so they move more slowly; this reduces both the frequency and the force of their collisions with the (fixed-area) walls of the cylinder, so the pressure they exert falls.

Bài tập luyện tập

Explain why the plateau on a cooling curve occurs at exactly the same temperature as the corresponding plateau on the heating curve of the same pure substance.

Lời giải chi tiết

The plateau always occurs at the melting/freezing point (or boiling/condensation point) of the substance, because this is the fixed temperature at which the forces of attraction between particles are exactly balanced against the energy being added or removed — energy changes the arrangement of the particles (breaking or re-forming these forces) rather than their temperature, whether the substance is being heated or cooled. Since it is the same pure substance, this balance point is identical in both directions.

Bài tập luyện tập

(Supplement) (a) A fixed mass of gas has a volume of $145\,\text{cm}^3$ at $27\,^\circ\text{C}$. At constant pressure, calculate its volume when heated to $87\,^\circ\text{C}$. (b) The same gas is then cooled, at constant pressure, from a volume of $250\,\text{cm}^3$ at $27\,^\circ\text{C}$ until its volume becomes $200\,\text{cm}^3$. Calculate the new Celsius temperature.

Lời giải chi tiết

(a) $T_1 = 27 + 273 = 300\,\text{K}$, $T_2 = 87 + 273 = 360\,\text{K}$.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \Rightarrow \frac{145}{300} = \frac{V_2}{360} \Rightarrow V_2 = \frac{145 \times 360}{300} = 174\,\text{cm}^3.$$

(b) $T_1 = 27 + 273 = 300\,\text{K}$.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \Rightarrow \frac{250}{300} = \frac{200}{T_2} \Rightarrow T_2 = \frac{200 \times 300}{250} = 240\,\text{K} = (240 - 273)\,^\circ\text{C} = -33\,^\circ\text{C}.$$

Bài tập luyện tập

(Supplement) A fixed mass of gas has a volume of $400\,\text{cm}^3$ at a pressure of $150\,\text{kPa}$ and a temperature of $47\,^\circ\text{C}$. Calculate its volume when its pressure is changed to $100\,\text{kPa}$ and its temperature to $27\,^\circ\text{C}$.

Lời giải chi tiết

$T_1 = 47 + 273 = 320\,\text{K}$, $T_2 = 27 + 273 = 300\,\text{K}$.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \Rightarrow \frac{(150)(400)}{320} = \frac{(100)V_2}{300} \Rightarrow V_2 = \frac{150 \times 400 \times 300}{320 \times 100} = 562.5\,\text{cm}^3.$$

Bài tập luyện tập

(a) State and explain, using kinetic particle theory, two factors that would increase the rate at which a puddle of rainwater on a pavement evaporates. (b) Explain why water boils at a lower temperature at the top of a high mountain than at sea level.

Lời giải chi tiết

(a) Any two of: **higher temperature** — raises the average kinetic energy of the water particles, so a larger fraction have enough energy to escape from the surface; **larger surface area** (e.g. the puddle spreading out thinly) — exposes more particles at the surface, giving more of them the chance to escape per second; **air movement/wind** — carries evaporated water vapour away from just above the puddle, keeping the vapour concentration there low and maintaining a fast net rate of evaporation; **low humidity** — the surrounding air is far from saturated with water vapour, so little vapour condenses back into the puddle.
(b) A liquid boils once its vapour pressure equals the external (atmospheric) pressure on its surface. Atmospheric pressure is lower at high altitude than at sea level, so the water's vapour pressure only needs to reach this lower value — which happens at a lower temperature — for boiling to begin.

Bài tập luyện tập

Explain, in terms of kinetic particle theory, why sweating helps to cool the human body on a hot day.

Lời giải chi tiết

Sweat is mostly water on the surface of the skin. Only the most energetic water particles have enough kinetic energy to escape as vapour (evaporate); once they leave, the particles remaining in the sweat have a lower average kinetic energy than before, so the temperature of the remaining liquid (and the skin beneath it) falls. This transfer of thermal energy away from the body, via evaporating sweat, is the cooling mechanism.

Bài tập luyện tập

(Supplement) A sealed, rigid flask contains a fixed mass of gas X ($M_r = 44$) at $20\,^\circ$C and 100 kPa. (a) The flask is placed in a water bath and heated to $80\,^\circ$C. Explain, using kinetic particle theory, what happens to the pressure inside the flask. (b) An identical second flask contains gas Y ($M_r = 4$) at the same initial temperature and pressure. Whose particles have the greater average speed, and why? (c) If both gases were allowed to escape simultaneously through identical small holes, calculate the ratio of the rate of escape of gas Y to that of gas X.

Lời giải chi tiết

(a) The pressure **increases**. Heating raises the average kinetic energy of the gas particles, so they move faster; because the flask is rigid (fixed volume), this increases both the frequency and the force of collisions with the walls, raising the pressure.
(b) Gas Y's particles move faster on average. At the same temperature both gases have the same average kinetic energy ($E_k = \frac{1}{2}mv^2$); since gas Y's particles have a much smaller mass ($M_r = 4$ versus $M_r = 44$), they must move faster to have that same kinetic energy.

(c) $\dfrac{\text{rate(Y)}}{\text{rate(X)}} = \sqrt{\dfrac{M_r(\text{X})}{M_r(\text{Y})}} = \sqrt{\dfrac{44}{4}} = \sqrt{11} \approx 3.32$. Gas Y escapes about **3.3 times** as fast as gas X.

Atoms, Elements and Compounds

Mục tiêu Unit: Cấu tạo nguyên tử (proton, neutron, electron); số hiệu nguyên tử Z và số khối A; đồng vị và khối lượng nguyên tử tương đối A_r; cấu hình electron theo lớp (shell) và mối liên hệ với nhóm/chu kỳ trong bảng tuần hoàn; sự hình thành ion (cation, anion); liên kết ion (mạng tinh thể khổng lồ); liên kết cộng hoá trị (phân tử đơn giản và mạng khổng lồ); liên kết kim loại (biển electron); phân biệt nguyên tố, hợp chất và hỗn hợp; và (Nâng cao) hạt nano — kích thước, tỉ lệ diện tích bề mặt/thể tích và ứng dụng.

2.1 Atomic structure

Every atom has a tiny, extremely dense, positively charged **nucleus** at its centre, containing **protons** and **neutrons** (collectively called *nucleons*), surrounded by fast-moving **electrons** arranged in **shells** (energy levels). Almost all of the mass of an atom is concentrated in the nucleus, while almost all of the *volume* of an atom is empty space occupied by the moving electrons: the diameter of the nucleus is roughly one ten-thousandth of the diameter of the whole atom, yet the nucleus contains over 99.9% of the atom's mass.

Particle	Relative mass	Relative charge
Proton	1	$+1$
Neutron	1	0
Electron	$\frac{1}{1840}$ (negligible)	-1

An atom is electrically **neutral** overall because it contains equal numbers of protons ($+$) and electrons ($-$); the neutrons contribute mass but no charge.

Proton number (atomic number), Z = number of protons in the nucleus = number of electrons in a neutral atom. Z identifies which element an atom is.
Nucleon number (mass number), A = number of protons + number of neutrons.
Number of neutrons $= A - Z$.
An atom is written in the form ${}^{A}_{Z}\mathrm{X}$, e.g. ${}^{23}_{11}\mathrm{Na}$ (11 protons, 12 neutrons, 11 electrons).

VN **GIẢI THÍCH TIẾNG VIỆT**

Nguyên tử gồm **hạt nhân** (chứa proton mang điện $+1$ và neutron trung hoà) ở giữa, và các **electron** (điện -1, khối lượng không đáng kể) chuyển động trong các **lớp electron** (shell) bao quanh. Nguyên tử trung hoà về điện vì số proton = số electron. **Số hiệu nguyên tử** Z = số proton = số electron. **Số khối** A = số proton + số neutron ⇒ số neutron $= A - Z$.

2.1.1 Isotopes and relative atomic mass

Isotopes are atoms of the *same* element (same proton number Z, so identical chemical behaviour) that have *different* numbers of neutrons, and therefore different mass numbers A. Because isotopes of an element have identical electron arrangements, they undergo exactly the same chemical reactions; but because they have different masses, their mass-dependent *physical* properties (density, rate of diffusion, and very slightly their melting/boiling points) differ.

Natural samples of most elements are mixtures of isotopes. The **relative atomic mass**, A_r, is the weighted mean mass of all the atoms in a naturally occurring sample of the element, taking into account both the mass number and the relative abundance (% present) of each isotope, compared with $\frac{1}{12}$ of the mass of an atom of ^{12}C:

$$A_r = \frac{\sum(\text{isotope mass number} \times \%\ \text{abundance})}{100}.$$

VN **GIẢI THÍCH TIẾNG VIỆT**

Đồng vị là các nguyên tử của cùng một nguyên tố (cùng Z) nhưng khác số neutron (khác A) $\Rightarrow$ tính chất hoá học giống hệt nhau (vì cấu hình electron giống nhau) nhưng tính chất vật lý phụ thuộc khối lượng (khối lượng riêng, tốc độ khuếch tán, điểm nóng chảy/sôi) có thể khác nhau chút ít. A_r là khối lượng nguyên tử tương đối, tính theo **trung bình có trọng số** của các đồng vị trong mẫu tự nhiên.

Ví dụ mẫu · Two-isotope A_r calculation

Chlorine occurs naturally as two isotopes: ^{35}Cl (75%) and ^{37}Cl (25%). Calculate the relative atomic mass of chlorine.

$$A_r = \frac{(35 \times 75) + (37 \times 25)}{100} = \frac{2625 + 925}{100} = \frac{3550}{100} = 35.5.$$

This matches the accepted value, $A_r(\text{Cl}) = 35.5$.

Ví dụ mẫu · Three-isotope A_r calculation

Magnesium occurs naturally as three isotopes: ^{24}Mg (79%), ^{25}Mg (10%) and ^{26}Mg (11%). Calculate the relative atomic mass of magnesium to 1 decimal place.

$$A_r = \frac{(24 \times 79) + (25 \times 10) + (26 \times 11)}{100} = \frac{1896 + 250 + 286}{100} = \frac{2432}{100} = 24.32 \approx 24.3.$$

This matches the accepted value, $A_r(\text{Mg}) = 24.3$.

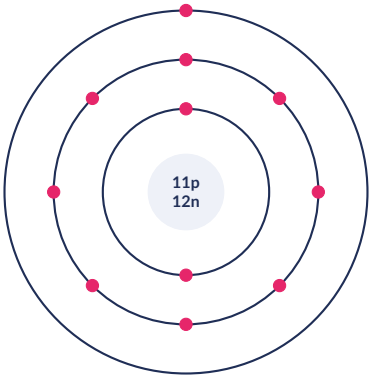


Figure 2.1 — Electronic structure of a sodium atom ($^{23}_{11}$Na), configuration $2, 8, 1$: 11 protons & 12 neutrons in the nucleus; 11 electrons across three shells (2 in shell 1, 8 in shell 2, 1 in shell 3).

(!) Lỗi thường gặp: Do not confuse the **mass number** A (a whole number, specific to one isotope, e.g. 35 for ^{35}Cl) with the **relative atomic mass** A_r (a weighted average across *all* isotopes in a natural sample, often *not* a whole number, e.g. $A_r(\text{Cl}) = 35.5$). A_r is what is printed on the Periodic Table; a single atom never actually has a mass number of 35.5 — only the statistical average of a large sample does.

Bài tập luyện tập

An atom of element X has 17 protons, 17 electrons and 20 neutrons. What is its nucleon (mass) number?

(A) 17
(B) 20
(C) 34
(D) 37

Lời giải chi tiết

Mass number A = protons + neutrons $= 17 + 20 =$ **37. (D).**

Bài tập luyện tập

Copper has two isotopes: ^{63}Cu (69%) and ^{65}Cu (31%). Calculate the relative atomic mass of this sample of copper to 1 decimal place.

Lời giải chi tiết

$$A_r = \frac{(63 \times 69) + (65 \times 31)}{100} = \frac{4347 + 2015}{100} = \frac{6362}{100} = 63.62 \approx 63.6,$$

close to the accepted value, 63.5.

Bài tập luyện tập

Silicon occurs naturally as three isotopes: ^{28}Si (92%), ^{29}Si (5%) and ^{30}Si (3%). Calculate the relative atomic mass of silicon to 1 decimal place.

Lời giải chi tiết

$$A_r = \frac{(28 \times 92) + (29 \times 5) + (30 \times 3)}{100} = \frac{2576 + 145 + 90}{100} = \frac{2811}{100} = 28.11 \approx 28.1,$$

consistent with the accepted value, 28.1.

Bài tập luyện tập

State one *physical* property that can differ between two isotopes of the same element, and one *chemical* property that is always identical for them. Explain why, in each case.

Lời giải chi tiết

Physical property that differs: density, rate of diffusion, or (very slightly) melting/boiling point — these depend on the *mass* of the atoms, and isotopes have different numbers of neutrons and so different masses.
Chemical property that is identical: reactivity / the type of reactions and bonds the element

forms — chemical behaviour is controlled by the number and arrangement of *electrons* (especially the outer shell), and isotopes of the same element have identical proton numbers and therefore identical electron configurations.

2.2 Electronic structure

Electrons occupy discrete **shells** (energy levels) around the nucleus. Electrons fill the shell *closest to the nucleus first* (the lowest available energy level), and each shell can only hold a limited number of electrons before the next shell begins to fill. Electrons cannot exist between shells — each shell corresponds to a fixed, allowed amount of energy, so an atom's electronic structure can always be written as a simple list of whole numbers.

For the first 20 elements, shells fill in the order shown, with maximum capacities:

- 1st shell (closest to nucleus): maximum **2** electrons;
- 2nd shell: maximum **8** electrons;
- 3rd shell: filled to **8** electrons before the 4th shell starts (its true maximum capacity, 18, is not reached until elements beyond calcium, which are outside the IGCSE syllabus);
- 4th shell: begins once the 3rd shell holds 8 electrons — so potassium ($Z = 19$) is $2, 8, 8, 1$ and calcium ($Z = 20$) is $2, 8, 8, 2$, *not* $2, 8, 9$ or $2, 8, 10$.

An electronic configuration is written as a list of numbers separated by commas, from the innermost shell outward, e.g. sodium ($Z = 11$) is $2, 8, 1$.

Z	Symbol	Configuration	Z	Symbol	Configuration
1	H	1	11	Na	2,8,1
2	He	2	12	Mg	2,8,2
3	Li	2,1	13	Al	2,8,3
4	Be	2,2	14	Si	2,8,4
5	B	2,3	15	P	2,8,5
6	C	2,4	16	S	2,8,6
7	N	2,5	17	Cl	2,8,7
8	O	2,6	18	Ar	2,8,8
9	F	2,7	19	K	2,8,8,1
10	Ne	2,8	20	Ca	2,8,8,2

VN **GIẢI THÍCH TIẾNG VIỆT**

Electron được sắp vào các **lớp** (shell) từ trong ra ngoài: lớp 1 tối đa 2 electron, lớp 2 tối đa 8, và với 20 nguyên tố đầu tiên, lớp 3 chỉ chứa tối đa 8 electron trước khi electron bắt đầu vào lớp 4 (dù lớp 3 thực ra chứa được tới 18 electron ở các nguyên tố xa hơn). Ví dụ: Na ($Z = 11$) có cấu hình $2, 8, 1$; K ($Z = 19$) có cấu hình $2, 8, 8, 1$ (không phải $2, 8, 9$).

2.2.1 Configuration, groups and periods

The Periodic Table is arranged so that elements with similar chemical properties fall in the same vertical column (**Group**), and each new horizontal row (**Period**) corresponds to a new outer electron shell beginning to fill.

Group number = number of electrons in the outermost (highest) occupied shell (elements with 1 outer electron are in Group I / Group 1, ..., elements with a full outer shell of 8 are in Group 0 / Group VIII, the noble gases; in the modern IUPAC numbering these correspond to Groups 13–18 for the p-block).
Period number = number of occupied electron shells.

Ví dụ mẫu · Configuration → group and period

An atom has proton number 15. Write its electronic configuration and state its period and group.
Filling shells $2, 8, 8, \ldots$: $2+8=10$, leaving $15-10=5$ electrons for the next shell. Configuration $= 2, 8, 5$.
Number of shells occupied $= 3 \Rightarrow$ **Period 3**. Outer-shell electrons $= 5 \Rightarrow$ **Group 5 (Group V)**. (This is phosphorus, P.)

Ví dụ mẫu · Configuration → group and period

An atom has proton number 19. Write its electronic configuration and state its period and group.
$2, 8$ uses 10 electrons; the 3rd shell fills to 8 (using 8 more, total 18); the remaining $19-18=1$ electron starts a new (4th) shell. Configuration $= 2, 8, 8, 1$.
Number of shells occupied $= 4 \Rightarrow$ **Period 4**. Outer-shell electrons $= 1 \Rightarrow$ **Group 1 (Group I)**. (This is potassium, K.)

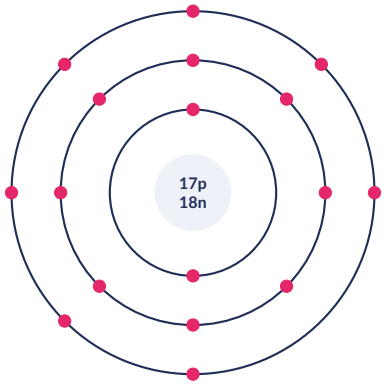


Figure 2.2 — Electronic structure of a chlorine atom ($^{35}_{17}$Cl), configuration $2, 8, 7$: 17 protons & 18 neutrons in the nucleus; the outer shell has 7 of a possible 8 electrons, one vacancy short of a full (noble-gas) shell.

VN **GIẢI THÍCH TIẾNG VIỆT**
Số electron ở lớp ngoài cùng quyết định **số nhóm** (Group); số lớp electron đang có electron quyết định **số chu kỳ** (Period). Ví dụ $Z = 15$ (photpho) có cấu hình $2, 8, 5$: 3 lớp $\Rightarrow$ chu kỳ 3; 5 electron lớp ngoài $\Rightarrow$ nhóm V.

Bài tập luyện tập

Write the full electronic configuration of magnesium ($Z = 12$) and state its period and group number.

Lời giải chi tiết

$2 + 8 = 10$, remaining $12 - 10 = 2$ electrons in the next shell $\Rightarrow$ configuration $2, 8, 2$. Shells occupied $= 3 \Rightarrow$ **Period 3**. Outer electrons $= 2 \Rightarrow$ **Group 2 (Group II)**.

Bài tập luyện tập

An atom has the electronic configuration $2, 8, 8, 2$. What are its period and group?

(A) Period 2, Group 2
(B) Period 4, Group 2
(C) Period 3, Group 8
(D) Period 4, Group 8

Lời giải chi tiết

Four shells are occupied $\Rightarrow$ Period 4; 2 electrons in the outer shell $\Rightarrow$ Group 2. **(B)** (this is calcium, $Z = 20$).

Bài tập luyện tập

Explain why calcium ($Z = 20$) has the electronic configuration $2, 8, 8, 2$ rather than $2, 8, 10$.

Lời giải chi tiết

For the first 20 elements, the third shell only fills up to 8 electrons before the fourth shell begins — even though the third shell can, at heavier elements beyond calcium, eventually hold up to 18 electrons. Once the third shell reaches 8 electrons (as in argon, $2, 8, 8$), the next electrons added (in potassium and calcium) start a new, fourth shell rather than continuing to fill the third. So calcium's 20 electrons are arranged $2, 8, 8, 2$, not $2, 8, 10$.

Bài tập luyện tập

An atom has proton number 16. Determine its electronic configuration, and hence state its period and group number.

Lời giải chi tiết

$2 + 8 = 10$ electrons placed, leaving $16 - 10 = 6$ electrons for the next shell $\Rightarrow$ configuration $2, 8, 6$. Three shells occupied $\Rightarrow$ **Period 3**. Six outer electrons $\Rightarrow$ **Group 6 (Group VI)**. (This is sulfur, S.)

2.3 Ions

An **ion** is a charged particle formed when an atom (or group of atoms) loses or gains electrons. Atoms react by transferring electrons in order to achieve the very stable electronic structure of a **noble gas** (a full outer shell: 2 for helium, or $2, 8$ / $2, 8, 8$ for the others) — this stability is the driving force behind ion formation and ionic bonding.

Metal atoms have few outer-shell electrons (Groups I–III) and **lose** them to form positively charged ions (**cations**), attaining the configuration of the noble gas *before* them.
Non-metal atoms have many outer-shell electrons (Groups V–VII) and **gain** electrons to form negatively charged ions (**anions**), attaining the configuration of the noble gas *after* them.
The charge on the ion equals the number of electrons transferred (with the appropriate sign): losing n electrons gives a charge of $n+$; gaining n electrons gives a charge of $n-$.

Atom (configuration)	e^- transferred	Ion	Ion configuration
Na $(2, 8, 1)$	loses 1	Na^+	$2, 8$ (= Ne)
Mg $(2, 8, 2)$	loses 2	Mg^{2+}	$2, 8$ (= Ne)
Al $(2, 8, 3)$	loses 3	Al^{3+}	$2, 8$ (= Ne)
O $(2, 6)$	gains 2	O^{2-}	$2, 8$ (= Ne)
Cl $(2, 8, 7)$	gains 1	Cl^-	$2, 8, 8$ (= Ar)
S $(2, 8, 6)$	gains 2	S^{2-}	$2, 8, 8$ (= Ar)

VN **GIẢI THÍCH TIẾNG VIỆT**
Ion là hạt mang điện, sinh ra khi nguyên tử **nhường** hoặc **nhận** electron để đạt cấu hình bền của khí hiếm (lớp ngoài đầy đủ). Kim loại (ít electron lớp ngoài) **nhường** electron ⇒ tạo **cation** (ion dương); phi kim (nhiều electron lớp ngoài) **nhận** electron ⇒ tạo **anion** (ion âm). Số electron trao đổi bằng đúng độ lớn điện tích của ion.

Ví dụ mẫu · Ion composition — Al^{3+}

An aluminium ion, Al^{3+}, is formed from an atom of $^{27}_{13}Al$. State the number of protons, neutrons and electrons in this ion, and its electronic configuration.

Protons $= 13$ (unchanged by ionisation). Neutrons $= 27 - 13 = 14$. The atom lost 3 electrons to form a $3+$ ion, so electrons $= 13 - 3 = 10$. Configuration of the ion: $2, 8$ — the same as neon.

Ví dụ mẫu · Ion composition — Cl^-

A chloride ion, Cl^-, is formed from an atom of $^{35}_{17}Cl$. State the number of protons, neutrons and electrons in this ion, and its electronic configuration.

Protons $= 17$ (unchanged). Neutrons $= 35 - 17 = 18$. The atom *gained* 1 electron to form a $1-$ ion, so electrons $= 17 + 1 = 18$. Configuration: $2, 8, 8$ — the same as argon.

Ví dụ mẫu · Ion composition — S^{2-}

A sulfide ion, S^{2-}, is formed from an atom of $^{32}_{16}S$. State the number of protons, neutrons and electrons in this ion, and its electronic configuration.

Protons $= 16$ (unchanged). Neutrons $= 32 - 16 = 16$. The atom gained 2 electrons to form a $2-$ ion, so electrons $= 16 + 2 = 18$. Configuration: $2, 8, 8$ — the same as argon.

(!) Lỗi thường gặp: A common electron-counting mistake: the **number of protons never changes** when an ion forms (that would change the element itself) — only the number of **electrons** changes. Also watch the sign: **losing** electrons leaves *more* protons than electrons, giving

a **positive** ion; **gaining** electrons gives *more* electrons than protons, giving a **negative** ion. Students frequently reverse this, or forget to adjust the electron count at all when asked for the composition of an ion rather than an atom.

Bài tập luyện tập

Sodium-23 forms the ion Na^{+}. State the number of protons, neutrons and electrons in this ion.

Lời giải chi tiết

Protons $= 11$ (unchanged). Neutrons $= 23 - 11 = 12$. Electrons $= 11 - 1 = 10$ (one electron lost to form the $1+$ ion).

Bài tập luyện tập

Calcium-40 forms the ion Ca^{2+}. State the number of protons, neutrons and electrons in this ion, and its electronic configuration.

Lời giải chi tiết

Protons $= 20$ (unchanged). Neutrons $= 40 - 20 = 20$. Electrons $= 20 - 2 = 18$ (two electrons lost). Configuration: $2, 8, 8$ — the same as argon.

Bài tập luyện tập

Fluorine-19 forms the ion F^{-}. How many protons, neutrons and electrons does this ion contain?

(A) 9, 9, 9
(B) 9, 10, 10
(C) 9, 10, 9
(D) 10, 9, 10

Lời giải chi tiết

Protons $= 9$ (unchanged). Neutrons $= 19 - 9 = 10$. Electrons $= 9 + 1 = 10$ (one electron gained). **(B)**.

Bài tập luyện tập

Explain, in terms of electron transfer and electronic structure, why sodium and chlorine react together to form Na^{+} and Cl^{-} ions rather than some other combination of charges.

Lời giải chi tiết

Sodium $(2, 8, 1)$ has just 1 electron in its outer shell; losing that single electron leaves it with the stable, full-outer-shell configuration $2, 8$ of neon, and a charge of $1+$. Chlorine $(2, 8, 7)$ has 7 outer electrons, one short of a full shell; gaining a single electron completes its outer shell to give the stable configuration $2, 8, 8$ of argon, and a charge of $1-$. Since sodium has exactly one electron to lose and chlorine has exactly one vacancy to fill, one electron transfers from each Na atom to each Cl atom, giving Na^{+} and Cl^{-} in a 1:1 ratio.

2.4 Ionic bonding

Ionic bonding is the strong electrostatic force of attraction between oppositely charged ions. It typically forms when a metal reacts with a non-metal: the metal atom(s) transfer outer-shell electrons to the non-metal atom(s), so that both end up with full (noble-gas) outer shells. The resulting ions pack together into a **giant ionic lattice**: a regular, repeating three-dimensional arrangement in which every positive ion is surrounded by several negative ions and vice versa, extending throughout the whole crystal.

For example, in the sodium chloride lattice each Na^+ ion is surrounded by 6 neighbouring Cl^- ions (and each Cl^- ion by 6 Na^+ ions), even though the formula NaCl shows only a simple 1:1 ratio. The formula of an ionic compound always gives the *simplest whole-number ratio* of the ions present in the lattice, not the number of nearest neighbours surrounding each ion.

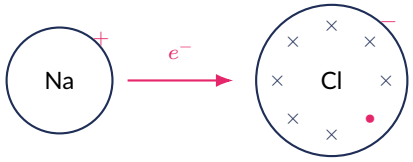


Figure 2.3 — Dot-and-cross diagram for NaCl: one electron transfers from the outer shell of Na to the outer shell of Cl, forming Na^+ $(2, 8)$ and Cl^- $(2, 8, 8)$ — both now have a full outer shell.

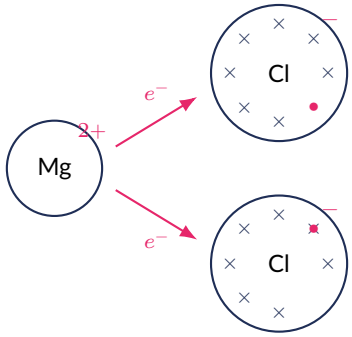


Figure 2.4 — Dot-and-cross diagram for $MgCl_2$: Mg $(2, 8, 2)$ loses *both* outer electrons, one to each of two separate Cl atoms $(2, 8, 7$ each). This forms one Mg^{2+} ion $(2, 8)$ and two Cl^- ions $(2, 8, 8$ each) — a 1:2 ratio of ions, giving the formula $MgCl_2$.

Further examples of electron transfer in ionic compounds:

- MgO: Mg $(2, 8, 2)$ transfers both outer electrons to a single O atom $(2, 6) \Rightarrow Mg^{2+}$ $(2, 8)$ and O^{2-} $(2, 8)$, in a 1:1 ratio.
- CaO: Ca $(2, 8, 8, 2)$ transfers both outer electrons to a single O atom $(2, 6) \Rightarrow Ca^{2+}$ $(2, 8, 8)$ and O^{2-} $(2, 8)$, in a 1:1 ratio.
- Na_2O: *two* Na atoms $(2, 8, 1$ each) each donate 1 electron to the *same* O atom $(2, 6)$, which needs 2 electrons to complete its outer shell $\Rightarrow$ two Na^+ ions $(2, 8$ each) and one O^{2-} ion $(2, 8)$, in a 2:1 ratio.

Ví dụ mẫu · Predicting an ionic formula

Aluminium forms Al^{3+} ions and oxygen forms O^{2-} ions. Use the charge-balance ("criss-cross") method to predict the formula of aluminium oxide.

The overall compound must be electrically neutral, so the total positive charge must equal the total negative charge. Using the numerical charge of each ion as the subscript of the *other* ion: Al^{3+} gives subscript 2 (from O^{2-}'s charge) and O^{2-} gives subscript 3 (from Al^{3+}'s charge).

Check: $2 \times (3+) + 3 \times (2-) = 6 + 6- = 0$. Formula: Al_2O_3.

Properties of ionic compounds, explained structurally:

- **High melting and boiling points** — the electrostatic forces of attraction between ions act strongly in all directions throughout the giant lattice, so a large amount of energy is needed to separate the ions.
- **Hard but brittle** — a blow that shifts one layer of ions slightly relative to the next brings ions of the *same* charge next to each other; the resulting repulsion splits the crystal along that plane.
- **Do not conduct electricity as solids** — the ions are held in fixed positions in the lattice and cannot move to carry charge.
- **Do conduct electricity when molten or dissolved in water (aqueous)** — the lattice breaks down (melting) or the ions are separated and surrounded by water molecules (dissolving), so the ions become free to move and carry charge.
- **Often soluble in water** — polar water molecules can surround and separate the individual ions from the lattice.

VN **GIẢI THÍCH TIẾNG VIỆT**

Liên kết ion là lực hút tĩnh điện mạnh giữa các ion trái dấu, tạo thành **mạng tinh thể ion khổng lồ**. Vì lực hút này tác động theo mọi hướng và rất mạnh trong toàn mạng $\Rightarrow$ nhiệt độ nóng chảy/sôi **cao**; tinh thể **cứng nhưng giòn** (khi lớp ion trượt, các ion cùng dấu chạm nhau, đẩy nhau, làm vỡ mạng); **không dẫn điện** ở trạng thái rắn (ion cố định), nhưng **dẫn điện** khi nóng chảy hoặc hoà tan trong nước (ion tự do di chuyển).

(!) Lỗi thường gặp: Do not mix up the rules for ionic and covalent bonding. **Ionic bonding** (metal + non-metal): electrons are **transferred** completely from one atom to another, producing charged ions. **Covalent bonding** (non-metal + non-metal): electrons are **shared** between atoms, and no ions are formed. A very common error is describing a covalent molecule as containing "ions", or describing an ionic lattice as "sharing" electrons between neighbouring ions — always check first whether the substance is a metal/non-metal combination (ionic) or a non-metal/non-metal combination (covalent).

Bài tập luyện tập

Calcium forms Ca^{2+} ions and chlorine forms Cl^- ions. Use the charge-balance method to predict the formula of calcium chloride.

Lời giải chi tiết

Charges: Ca is $2+$, Cl is $1-$. Cross the numerical charges as subscripts: Ca needs subscript 1 (from Cl's charge, 1), Cl needs subscript 2 (from Ca's charge, 2). Check: $1 \times (2+) + 2 \times (1-) = 2 + 2- = 0$. Formula: $CaCl_2$.

Bài tập luyện tập

Which property is *not* typical of ionic compounds?

(A) High melting point
(B) Good electrical conductor when molten
(C) Good electrical conductor when solid
(D) Often soluble in water

Lời giải chi tiết

Ionic solids do not conduct electricity because their ions are fixed in the lattice and cannot move to carry charge; conduction only occurs once the ions are freed, by melting or dissolving. **(C)**.

Bài tập luyện tập

Explain, in terms of structure, why ionic crystals are brittle and shatter rather than bend when struck.

Lời giải chi tiết

An ionic lattice consists of alternating layers of positive and negative ions held together by electrostatic attraction between unlike charges. A sharp blow can shift one layer of ions by a small distance relative to the layer next to it. This can bring ions of the *same* charge into direct contact; like charges strongly **repel** each other, and this repulsion forces the layers apart, splitting (cleaving) the crystal along that plane rather than allowing it to deform.

Bài tập luyện tập

Describe, in words, the ionic bonding in Na_2O, stating the electronic configurations of the ions formed.

Lời giải chi tiết

Two sodium atoms ($2, 8, 1$ each) each lose their single outer electron; both electrons transfer to the same oxygen atom ($2, 6$), which needs exactly 2 electrons to complete its outer shell. This produces two Na^+ ions, each with configuration $2, 8$ (the same as neon), and one O^{2-} ion with configuration $2, 8$ (also the same as neon). The ions are present in a 2:1 ratio, giving the formula Na_2O.

2.5 Covalent bonding

Covalent bonding occurs between non-metal atoms, which *share* one or more pairs of electrons so that each atom attains a full outer shell (8 electrons, or 2 for hydrogen). A single shared pair is a **single bond**; two shared pairs form a **double bond**; three shared pairs form a **triple bond** ((Supplement)). In general, a triple bond is shorter and stronger than a double bond, which is in turn shorter and stronger than a single bond.

Simple covalent molecules — dot-and-cross summary:

- H_2: each H atom has 1 electron; one shared pair (single bond) gives both atoms a full duplet of 2.
- Cl_2: each Cl atom $(2, 8, 7)$ has 7 outer electrons; one shared pair completes both outer shells to 8.
- O_2: each O atom $(2, 6)$ has 6 outer electrons; **two** shared pairs (a double bond) complete both outer shells to 8.
- N_2 (**(Supplement)**): each N atom $(2, 5)$ has 5 outer electrons; **three** shared pairs (a triple bond) complete both outer shells to 8.
- CO_2: carbon $(2, 4)$ forms a double bond (C = O) with *each* of the two oxygen atoms, giving carbon 8 shared electrons and each oxygen a full outer shell of 8.
- CH_4: carbon $(2, 4)$ forms 4 single bonds, one to each hydrogen atom, giving carbon a full outer shell of 8 and each H a full duplet of 2.
- NH_3: nitrogen $(2, 5)$ forms 3 single bonds to the 3 hydrogen atoms, using 3 of its 5 outer electrons; the remaining 2 electrons stay as a non-bonding **lone pair** on N, which still ends up with a full outer shell of 8 (3 bonding pairs + 1 lone pair).
- H_2O: oxygen $(2, 6)$ forms 2 single bonds to the 2 hydrogen atoms and keeps 2 lone pairs, giving oxygen a full outer shell of 8.

VN **GIẢI THÍCH TIẾNG VIỆT**

Liên kết cộng hoá trị: hai phi kim **góp chung** một hay nhiều cặp electron để cả hai đạt đủ 8 electron lớp ngoài (hoặc 2 với hydro). 1 cặp góp chung = liên kết **đơn**; 2 cặp = liên kết **đôi** (như O_2); 3 cặp = liên kết **ba** (như N_2, Nâng cao). Trong NH_3 và H_2O, một số electron lớp ngoài không tham gia liên kết mà tồn tại thành **cặp electron riêng** (lone pair).

Ví dụ mẫu · Dot-and-cross reasoning for CO_2

Carbon dioxide has the formula CO_2. Use electronic configurations to explain how each atom attains a full outer shell, and state the total number of covalent bonds in one molecule.

Carbon $(2, 4)$ has 4 outer electrons; each oxygen atom $(2, 6)$ has 6 outer electrons. Carbon forms a **double** bond (2 shared pairs) with *each* of the two oxygen atoms: this uses all 4 of carbon's outer electrons (2 in each double bond), giving carbon a full outer shell of 8 (4 shared pairs $\times$ 2 electrons). Each oxygen atom contributes 2 of its own electrons to its double bond with carbon and keeps 2 non-bonding lone pairs, giving each oxygen a full outer shell of 8 as well. In total there are **2 double bonds** (O = C = O), i.e. 4 shared pairs = 8 shared electrons overall.

2.5.1 Simple molecular vs. giant covalent structures

Simple molecular substances (e.g. H_2O, CO_2, CH_4, Cl_2) consist of individual small molecules. The covalent bonds *within* each molecule are strong, but the forces of attraction *between* separate molecules (intermolecular forces) are weak. Melting or boiling such a substance only requires overcoming these weak intermolecular forces (not breaking any covalent bonds), so simple molecular substances have **low melting and boiling points** and, having no free ions or electrons, do **not conduct electricity**.

Giant covalent (macromolecular) structures (e.g. diamond, graphite, silicon(IV) oxide, SiO_2) consist of enormous numbers of atoms joined in a continuous three-dimensional (or layered) network of strong covalent bonds, with no separate small molecules at all. Melting such a structure means

breaking a vast number of strong covalent bonds throughout the lattice, so giant covalent structures have **very high melting points** and are typically very hard.

Property	Diamond	Graphite	Silicon(IV) oxide, SiO_2
Bonding per atom	4 covalent bonds (C)	3 covalent bonds (C)	4 (Si)/2 (O) covalent bonds
Structure	rigid 3-D tetrahedral	flat hexagonal layers	rigid 3-D tetrahedral (like diamond)
Forces between layers	— (no layers)	weak between layers	— (no layers)
Melting point	very high	very high (decomposes)	very high
Hardness	extremely hard	soft, slippery, flakes	hard
Electrical conductivity	does not conduct	conducts (along layers)	does not conduct
Typical use	cutting/drilling tools	lubricant, pencil "lead"	glass, sand, ceramics

Table 2.1 — Structural comparison of the three giant covalent structures most often compared at IGCSE.

In **diamond**, every carbon atom uses *all four* of its outer-shell electrons to form 4 strong covalent bonds to 4 neighbouring carbon atoms, so there are no free (delocalised) electrons — diamond does *not* conduct electricity. In **graphite**, each carbon atom forms only 3 covalent bonds (to 3 neighbours within a flat hexagonal layer); the *4th* outer electron of each carbon atom is not used in bonding and becomes **delocalised**, free to move along the layers — this is why graphite *does* conduct electricity. The layers themselves are held together only by weak forces, allowing them to slide over one another — this is why graphite is soft and slippery (used as a lubricant and in pencils), unlike the rigid 3-D covalent network of diamond.

Ví dụ mẫu · Diamond, graphite and silicon(IV) oxide

Explain why graphite conducts electricity but diamond and silicon(IV) oxide do not, even though all three are giant covalent structures.

Electrical conduction requires charge carriers (free ions or free/delocalised electrons) able to move through the structure. In diamond, every one of carbon's 4 outer electrons is used to form a covalent bond, so none are free to move — no conduction. In silicon(IV) oxide, every outer electron of Si and O is likewise used in covalent bonds (Si forms 4 bonds, O forms 2), so again there are no free charge carriers — no conduction. In graphite, each carbon only forms 3 covalent bonds within its layer; the 4th outer electron of every carbon atom is delocalised and free to move *along* the layers, carrying charge — so graphite conducts, but only in the direction of the layers.

(!) Lỗi thường gặp: It is a common error to think that the *low* melting point of simple molecular substances means their covalent bonds are weak. In fact the covalent bonds *within* the molecule (e.g. O = O in O_2) are strong; it is only the much weaker forces *between* separate molecules that are overcome on melting or boiling. Never describe a low melting point as evidence of "weak covalent bonding" — say instead that the intermolecular forces are weak.

Bài tập luyện tập

In an oxygen molecule, O_2, the two atoms are joined by a double covalent bond. How many electrons in total are shared between the two atoms?

(A) 1
(B) 2
(C) 4
(D) 8

Lời giải chi tiết

A double bond is two shared pairs of electrons $= 2 \times 2 =$ **4 electrons** shared in total (2 contributed by each atom). **(C)**.

Bài tập luyện tập

(Supplement) In a nitrogen molecule, N_2, the two atoms are joined by a triple covalent bond. How many electrons in total are shared between the two atoms, and how many does each atom contribute?

Lời giải chi tiết

A triple bond is three shared pairs of electrons $= 3 \times 2 =$ **6 electrons** shared in total, with each nitrogen atom contributing 3 of its 5 outer electrons to the shared pairs (leaving one lone pair on each N atom, giving both atoms a full outer shell of 8).

Bài tập luyện tập

Describe the covalent bonding in a molecule of ammonia, NH_3, stating the number of shared (bonding) pairs and the number of lone pairs of electrons.

Lời giải chi tiết

Nitrogen $(2, 5)$ forms one single covalent bond to each of the 3 hydrogen atoms, using 3 of its 5 outer electrons in 3 shared (bonding) pairs. The remaining 2 outer electrons of nitrogen form 1 non-bonding **lone pair**. This gives nitrogen a full outer shell of 8 electrons (3 bonding pairs $+$ 1 lone pair $= 4$ pairs $= 8$ electrons), and each hydrogen atom a full duplet of 2 electrons.

Bài tập luyện tập

Which statement best explains why silicon(IV) oxide has an extremely high melting point?

(A) It has weak intermolecular forces that must be overcome

(B) It has strong covalent bonds throughout a giant 3-D lattice that must be broken

(C) It contains free ions that must be separated

(D) It contains delocalised electrons that must be removed

Lời giải chi tiết

Silicon(IV) oxide is a giant covalent (macromolecular) structure: every Si and O atom is joined into a continuous 3-D network by strong covalent bonds. Melting requires breaking a huge number of these strong bonds throughout the whole lattice, which needs a very large amount of energy. **(B)**.

Bài tập luyện tập

(Supplement) Explain, referring to structure and bonding, why graphite is useful as a lubricant and in pencils, while diamond is useful in cutting and drilling tools.

Lời giải chi tiết

Graphite consists of flat layers of carbon atoms, each covalently bonded to only 3 neighbours within its layer; the layers themselves are held together by weak forces only, so they can slide easily over one another and flake off — this makes graphite soft and slippery, useful as a lubricant and as pencil "lead" (layers rub off onto paper). Diamond has no layers: every carbon atom is covalently bonded to 4 neighbours in a rigid three-dimensional tetrahedral network, with strong covalent bonds running in every direction. This makes diamond extremely hard and resistant to being cut or scratched, so it is used to tip cutting and drilling tools.

2.6 Metallic bonding

Metal atoms are packed into a giant lattice of positively charged **metal ions**. The electrons from the outer shell of every metal atom are not attached to any one atom but are **delocalised** — free to move throughout the entire structure, forming a mobile "sea" of electrons that holds the whole lattice together by strong electrostatic attraction between the negative electron sea and the positive ions.

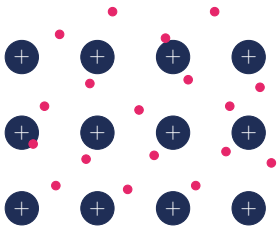


Figure 2.5 — Metallic bonding: a giant lattice of positive metal ions (navy circles, "+") immersed in a mobile "sea" of delocalised outer-shell electrons (pink dots), free to move throughout the whole structure.

Properties of metals, explained by metallic bonding:

- **Good electrical conductors** (as solids *and* liquids) — the delocalised electrons are free to move throughout the structure and carry charge, without the lattice needing to melt or dissolve first.
- **Good thermal conductors** — the mobile electrons can also transfer kinetic energy rapidly through the structure.
- **Malleable and ductile** (can be hammered into sheets or drawn into wires) — the layers of positive ions can slide over one another into new positions without breaking any specific, directional bond; the mobile electron sea simply flows to re-surround the ions in their new positions, keeping the metallic bonding intact.
- **Generally high melting points** — the electrostatic attraction between the positive ions and the delocalised electron sea is strong and acts throughout the giant structure, so a great deal of energy is needed to separate the ions.

VN **GIẢI THÍCH TIẾNG VIỆT**

Liên kết kim loại: các ion kim loại dương xếp thành mạng khổng lồ, được bao quanh bởi "biển" electron lớp ngoài **tự do di chuyển** (delocalised) khắp cấu trúc. Electron tự do giúp kim loại **dẫn điện, dẫn nhiệt tốt** (kể cả ở trạng thái rắn); các lớp ion có thể **trượt qua nhau** mà không phá vỡ liên kết ⇒ kim loại **dẻo, dễ dát mỏng/kéo sợi**; lực hút tĩnh điện mạnh giữa ion và biển electron trên toàn mạng ⇒ nhiệt độ nóng chảy thường **cao**.

Bài tập luyện tập

Why do metals conduct electricity in the solid state, unlike ionic solids?

(A) Metal ions are negatively charged

(B) Delocalised electrons are free to move through the whole structure and carry charge, even in the solid

(C) Metals contain free-moving ions, like molten ionic compounds

(D) Metal atoms are much smaller than non-metal atoms

Lời giải chi tiết

In a metal, outer-shell electrons are delocalised and can move freely through the entire lattice even while the ions themselves stay in fixed positions — this is different from an ionic solid, where it is the (fixed) ions, not electrons, that would need to move, and they cannot in the solid state. **(B)**.

Bài tập luyện tập

Explain, in terms of structure and bonding, why metals are malleable and ductile whereas ionic solids are brittle.

Lời giải chi tiết

In a metal, the bonding is not directional: it comes from the general attraction between the mobile sea of delocalised electrons and the positive ions. If a force causes one layer of ions to slide over another, the electron sea simply redistributes to continue surrounding the ions in their new positions, so the metallic bond is not broken — the metal bends or stretches (malleable/ductile). In an ionic solid, the bonding is between specific alternating layers of positive and negative ions. If a layer shifts, ions of the *same* charge are brought next to each other; the strong repulsion between like charges shatters the crystal rather than letting it deform — ionic solids are brittle.

Bài tập luyện tập

Explain why metals generally have high melting points.

Lời giải chi tiết

The positive metal ions are held in the lattice by strong electrostatic attraction to the surrounding sea of delocalised electrons, and this attraction acts throughout the entire giant structure (not just between two specific atoms). A large amount of thermal energy is therefore needed to overcome these forces and allow the ions to move apart from their fixed lattice positions, giving metals generally high melting points.

Tổng hợp · Comparing the three types of bonding

Feature	Ionic	Covalent (simple)	Metallic
Particles involved	metal + non-metal	non-metal + non-metal	metal atoms only
What happens to electrons	transferred (ions form)	shared (no ions)	delocalised (sea of e^-)
Structure	giant lattice of ions	individual small molecules	giant lattice of ions + e^-
Melting point	high	low	usually high
Conducts as a solid?	no	no	yes
Conducts molten/aqueous?	yes	no	yes (as solid already)

VN **GIẢI THÍCH TIẾNG VIỆT**

Bảng tổng hợp giúp phân biệt nhanh 3 loại liên kết: **ion** (kim loại + phi kim, electron bị **nhường/nhận**, mạng ion khổng lồ, không dẫn điện khi rắn); **cộng hoá trị đơn giản** (phi kim + phi kim, electron được **góp chung**, phân tử riêng lẻ, nhiệt độ nóng chảy thấp, không dẫn điện); **kim loại** (chỉ có nguyên tử kim loại, electron lớp ngoài **tự do** thành biển electron, dẫn điện ngay cả ở trạng thái rắn).

Bài tập luyện tập

Complete the comparison: which type of bonding (ionic, simple covalent, or metallic) is present in each of the following, and why? (a) magnesium oxide, MgO; (b) methane, CH_4; (c) copper wire.

Lời giải chi tiết

(a) **Ionic** — Mg (a metal) transfers electrons to O (a non-metal), forming Mg^{2+} and O^{2-} ions held in a giant lattice.
(b) **Simple covalent** — carbon and hydrogen (both non-metals) share electron pairs within individual CH_4 molecules.
(c) **Metallic** — copper atoms are held in a lattice of positive ions surrounded by a sea of delocalised electrons, which is also why the wire conducts electricity.

2.7 Elements, compounds and mixtures

Element: a substance made of only one type of atom (all atoms have the same proton number); it cannot be broken down into anything simpler by chemical means.
Compound: a substance formed when two or more different elements are chemically combined together in a *fixed* ratio; its properties are usually completely different from those of its constituent elements, and it can only be separated back into its elements by a chemical reaction.
Mixture: two or more elements and/or compounds that are physically mixed together but *not* chemically combined, in *no fixed* ratio; each component keeps its own original properties, and the components can be separated by purely **physical** methods (e.g. filtration, distillation, chromatography, evaporation, using a magnet).

Examples: elements — O_2, iron, sodium; compounds — H_2O, NaCl, CO_2; mixtures — air, sea water, crude oil.

Criterion	Element	Compound	Mixture
Composition ratio	fixed (one atom type)	fixed	variable
Chemically combined?	—	yes	no
Separable by physical means?	—	no (chemical only)	yes
Properties of components retained?	—	no (new properties)	yes

VN **GIẢI THÍCH TIẾNG VIỆT**

Nguyên tố: chỉ gồm một loại nguyên tử (cùng số proton), không thể tách nhỏ hơn bằng phương pháp hoá học. **Hợp chất**: hai hay nhiều nguyên tố **kết hợp hoá học** theo tỉ lệ **cố định**, tính chất khác hẳn các nguyên tố ban đầu, chỉ tách được bằng **phản ứng hoá học**. **Hỗn hợp**: các chất trộn lẫn về mặt **vật lý**, tỉ lệ **không cố định**, mỗi chất vẫn giữ tính chất riêng, và có thể tách bằng phương pháp **vật lý** (lọc, chưng cất, sắc ký,...).

2.7.1 Nanoparticles (Supplement)

Nanoparticles are extremely small clusters of matter, typically containing only a few hundred atoms, with at least one dimension roughly in the range 1–100 nanometres ($1\text{ nm} = 1\times10^{-9}$ m) — far smaller than everyday ("bulk") particles of the same substance, yet still much larger than a single atom or simple molecule.

As a particle gets smaller, its **surface-area-to-volume ratio** increases dramatically, because surface area scales with (length)^2 while volume scales with (length)^3. Nanoparticles therefore have an enormously higher proportion of their atoms exposed at the surface compared with bulk material of the same mass. This changes their properties: nanoparticles can be more chemically reactive per unit mass, absorb/scatter light differently, and have different mechanical or electrical behaviour compared with the same substance in bulk form. Applications include:

- **Catalysts** — a much greater fraction of the (often expensive) catalyst atoms are exposed at the surface where reactions actually occur, so less material is needed for the same catalytic effect.
- **Sunscreens** — nanoparticle titanium dioxide/zinc oxide reflect and absorb UV light just as effectively as larger particles of the same substances, but are small enough to be transparent on the skin rather than leaving a visible white layer.
- **Medicine** — engineered nanoparticles can be small enough to cross biological membranes and be targeted to specific cells, for example to deliver a drug directly to a tumour.

VN **GIẢI THÍCH TIẾNG VIỆT**

Hạt nano ((Supplement)) là các cụm hạt rất nhỏ, chỉ chứa vài trăm nguyên tử, kích thước khoảng 1–100 nanomet. Vì diện tích bề mặt tỉ lệ với (chiều dài)^2 còn thể tích tỉ lệ với (chiều dài)^3, hạt càng nhỏ thì **tỉ lệ diện tích bề mặt/thể tích càng lớn** $\Rightarrow$ hạt nano phản ứng/tương tác mạnh hơn hẳn so với cùng khối lượng vật liệu dạng khối (bulk). Ứng dụng: làm **chất xúc tác** hiệu quả hơn (tiết kiệm kim loại quý), làm **kem chống nắng** (hạt nano trong suốt trên da nhưng vẫn chặn tia UV), và trong **y học** (đưa thuốc trúng đích đến tế bào cụ thể).

Ví dụ mẫu · Surface-area-to-volume ratio (Supplement)

Compare the surface-area-to-volume ratio of a bulk cube-shaped particle of edge length 1 cm with a nanoparticle cube of the same substance with edge length 10 nm ($1\text{ nm} = 1\times10^{-7}$ cm). By what factor does the ratio increase?

For a cube of edge length L: surface area $= 6L^2$, volume $= L^3$, so ratio $= \dfrac{6L^2}{L^3} = \dfrac{6}{L}$.

Bulk cube, $L_1 = 1\,\text{cm}$: ratio $= \dfrac{6}{1} = 6\,\text{cm}^{-1}$.

Nanoparticle cube, $L_2 = 10\,\text{nm} = 1 \times 10^{-6}\,\text{cm}$: ratio $= \dfrac{6}{1 \times 10^{-6}} = 6 \times 10^{6}\,\text{cm}^{-1}$.

Factor of increase $= \dfrac{6 \times 10^{6}}{6} = 1 \times 10^{6}$. The nanoparticle has a surface-area-to-volume ratio **one million times** greater than the bulk particle.

(!) Lỗi thường gặp: Do not assume that a nanoparticle simply behaves like "a smaller piece of the same stuff." The key reason nanoparticle properties differ from bulk properties is the huge **increase in surface-area-to-volume ratio**, which changes what fraction of atoms are exposed at reactive surfaces — it is not merely that the particles are small, but that this specific ratio changes so dramatically as size decreases.

Bài tập luyện tập

Classify sea water as an element, a compound, or a mixture. Justify your answer.

(A) Element
(B) Compound
(C) Mixture
(D) Pure substance

Lời giải chi tiết

Sea water contains water and various dissolved salts (and gases) in a ratio that varies from place to place; the dissolved substances are not chemically combined with the water and can be separated from it by physical means (e.g. distillation or evaporation). **(C) Mixture**.

Bài tập luyện tập

Explain the key difference between a compound and a mixture, giving one distinguishing feature based on composition and one based on how the components can be separated.

Lời giải chi tiết

Composition: a compound has its elements chemically combined in a fixed ratio by mass; a mixture has its components present in any (variable) ratio, with no chemical combination between them.
Separation: the elements of a compound can only be separated by a chemical reaction (breaking chemical bonds); the components of a mixture can be separated by purely physical methods, such as filtration, distillation or chromatography, since no chemical bonds hold them together.

Bài tập luyện tập

(Supplement) A catalyst is manufactured as gold nanoparticle cubes of edge length $5\,\text{nm}$, instead of using bulk gold cubes of edge length $1\,\text{cm}$. Calculate the factor by which the surface-area-to-volume ratio increases when using the nanoparticles instead of the bulk gold (use $1\,\text{nm} = 1 \times 10^{-7}\,\text{cm}$).

Lời giải chi tiết

Ratio for a cube of edge L is $\frac{6}{L}$.

Bulk: $L_1 = 1$ cm, ratio $= \frac{6}{1} = 6\,\text{cm}^{-1}$.

Nanoparticle: $L_2 = 5\,\text{nm} = 5 \times 10^{-7}$ cm, ratio $= \frac{6}{5 \times 10^{-7}} = 1.2 \times 10^{7}\,\text{cm}^{-1}$.

Factor of increase $= \frac{1.2 \times 10^{7}}{6} = 2 \times 10^{6}$. The surface-area-to-volume ratio increases by a factor of **two million** — twice the increase seen for a 10 nm cube, since halving the edge length doubles the ratio (ratio $\propto 1/L$).

Bài tập luyện tập

(Supplement) Explain why using a catalyst in the form of nanoparticles, rather than as a single bulk lump of the same mass, generally makes the catalyst more efficient.

Lời giải chi tiết

A catalyst can only speed up a reaction at the surface where it is in contact with the reacting particles. Splitting the same mass of catalyst into many nanoparticles enormously increases its total surface-area-to-volume ratio, so a much greater proportion of its atoms are exposed at a surface where they can take part in catalysis. This means the same catalytic effect can be achieved using far less material (important for expensive catalysts such as platinum), and reactions proceed faster because more active surface is available to the reactants.

Bài tập luyện tập

Element Q has the electronic configuration $2, 8, 2$.
(a) State the period and group of Q.
(b) Is Q a metal or a non-metal? Explain your answer.
(c) Q reacts with chlorine. Using ion charges, predict the formula of the compound formed.

Lời giải chi tiết

(a) Three shells occupied $\Rightarrow$ **Period 3**; 2 outer electrons $\Rightarrow$ **Group 2 (Group II)**. (This is magnesium, Mg.)
(b) **Metal.** It has only 2 electrons in its outer shell — few enough to lose easily and attain a full outer shell (noble-gas structure), which is characteristic of metals; non-metals instead tend to gain electrons.
(c) Q loses 2 electrons to form Q^{2+}; chlorine $(2, 8, 7)$ gains 1 electron to form Cl^{-}. Balancing charges (crossing the numerical charges as subscripts): 1 Q^{2+} needs 2 Cl^{-} to balance, giving the formula QCl_2 (i.e. $MgCl_2$).

Bài tập luyện tập

Bromine occurs naturally as two isotopes, ^{79}Br (51%) and ^{81}Br (49%).
(a) Calculate the relative atomic mass of bromine to 1 decimal place.
(b) A bromide ion, Br^{-}, forms from an atom of $^{79}_{35}$Br. State the number of protons, neutrons and electrons in this ion.

Lời giải chi tiết

(a) $A_r = \dfrac{(79 \times 51) + (81 \times 49)}{100} = \dfrac{4029 + 3969}{100} = \dfrac{7998}{100} = 79.98 \approx 80.0$, close to the accepted value, 79.9.
(b) Protons $= 35$ (unchanged). Neutrons $= 79 - 35 = 44$. Electrons $= 35 + 1 = 36$ (one electron gained to form the $1-$ ion).

Stoichiometry

Mục tiêu Unit: Sau khi học xong Unit này, học viên có thể: tính khối lượng nguyên tử/phân tử tương đối (A_r, M_r) và số mol; lập công thức thực nghiệm và công thức phân tử từ dữ liệu phần trăm khối lượng và dữ liệu đốt cháy; cân bằng phương trình hoá học theo phương pháp hệ thống và viết phương trình ion rút gọn; áp dụng phương pháp 4 bước để tính toán theo phương trình hoá học (khối lượng, thể tích khí ở điều kiện phòng, nồng độ dung dịch); xác định chất phản ứng hết (limiting reactant) và tính hiệu suất phần trăm; tính nồng độ mol/dm^3 và g/dm^3, giải bài toán chuẩn độ kể cả với axit hai lần axit; tính độ tinh khiết phần trăm, xác định công thức ngậm nước tinh thể và giải bài toán pha loãng dung dịch.

3.1 Relative masses and the mole

Atoms are far too small to weigh individually — a single carbon atom has a mass of only about 1.99×10^{-23} g. Chemists therefore compare the masses of atoms to a standard: one-twelfth of the mass of an atom of carbon-12. This comparison produces the **relative atomic mass**, A_r.

Most elements exist as a mixture of **isotopes** — atoms with the same number of protons but different numbers of neutrons, and therefore slightly different masses. The value of A_r printed in the Periodic Table is a weighted average that already accounts for the natural abundance of each isotope, which is why, for example, chlorine's A_r (35.5) is not a whole number even though every individual atom has a whole number of protons and neutrons.

Relative atomic mass and relative molecular/formula mass

Relative atomic mass (A_r): the average mass of one atom of an element compared with one-twelfth of the mass of one atom of carbon-12 (taking into account the relative abundances of any isotopes of the element). A_r has no units.

Relative molecular mass (M_r) (for simple molecules) or **relative formula mass** (for giant ionic/-covalent structures such as NaCl or SiO_2): the sum of the A_r values of every atom shown in the chemical formula.

$$M_r(\text{CaCO}_3) = A_r(\text{Ca}) + A_r(\text{C}) + 3 \times A_r(\text{O}) = 40 + 12 + 3(16) = 100$$

Brackets multiply everything inside them by the subscript that follows, e.g. $M_r(\text{Ca(OH)}_2) = 40 + 2(16 + 1) = 74$.

VN **GIẢI THÍCH TIẾNG VIỆT**

A_r (khối lượng nguyên tử tương đối) so sánh khối lượng một nguyên tử với $1/12$ khối lượng của một nguyên tử carbon-12 — đây là một tỉ số nên **không có đơn vị**. M_r (khối lượng phân tử/công thức tương đối) là tổng tất cả các A_r có trong công thức hoá học, lưu ý dấu ngoặc nhân với chỉ số phía sau nó. Hai đại lượng này là nền tảng để chuyển đổi khối lượng $\leftrightarrow$ số mol trong mọi bài toán định lượng.

The **mole** (mol) is the SI base unit for "amount of substance." One mole of any substance contains exactly as many elementary particles (atoms, molecules, ions or formula units) as there are atoms in

exactly 12 g of carbon-12 — a number known as the **Avogadro constant**, N_A:

$$N_A = 6.02 \times 10^{23} \text{ particles per mole}$$

$$n = \frac{m}{M_r} \quad \Longleftrightarrow \quad m = n \times M_r \quad \Longleftrightarrow \quad \text{number of particles} = n \times N_A$$

where n = amount in moles (mol), m = mass (g), M_r = relative molecular/formula mass, and $N_A = 6.02 \times 10^{23}$ mol^{-1}.

VN **GIẢI THÍCH TIẾNG VIỆT**

Số mol = khối lượng $\div M_r$ (và ngược lại, khối lượng = số mol $\times M_r$). Một mol của bất kỳ chất nào — dù là nguyên tử, phân tử hay ion — cũng chứa đúng 6.02×10^{23} hạt (hằng số Avogadro). Công thức $n = m/M_r$ là công cụ trung tâm, xuất hiện trong **mọi** dạng bài của chương này.

Ví dụ mẫu · Worked example

Calculating M_r. Calculate the relative formula mass of ammonium sulfate, $(NH_4)_2SO_4$.

The formula contains 2 nitrogen atoms, 8 hydrogen atoms (2×4), 1 sulfur atom and 4 oxygen atoms.

$$M_r = 2(14) + 8(1) + 32 + 4(16) = 28 + 8 + 32 + 64 = 132$$

Reference table — common relative atomic and formula masses (A_r: H=1, C=12, N=14, O=16, Na=23, Mg=24, Al=27, S=32, Cl=35.5, K=39, Ca=40, Fe=56, Cu=64, Zn=65, Ag=108, Ba=137)

Substance	M_r	Substance	M_r	Substance	M_r
H_2O	18	HCl	36.5	NH_3	17
CO_2	44	H_2SO_4	98	CH_4	16
NaOH	40	$CaCO_3$	100	O_2 / N_2	32 / 28
NaCl	58.5	Na_2CO_3	106	$CuSO_4$	160
$MgSO_4$	120	$CuSO_4.5H_2O$	250	$Ca(OH)_2$	74

Bài tập luyện tập

What is the relative formula mass, M_r, of ammonium nitrate, NH_4NO_3?

(A) 60 **(C)** 80

(B) 70 **(D)** 90

Lời giải chi tiết

$M_r = 2(14) + 4(1) + 3(16) = 28 + 4 + 48 = 80$. **(C).**

Bài tập luyện tập

How many moles of atoms are there in 5.6 g of iron, Fe ($A_r = 56$)?

Lời giải chi tiết

$n = \dfrac{m}{A_r} = \dfrac{5.6}{56} = 0.1$ mol.

Bài tập luyện tập

Approximately how many particles are there in 0.5 mol of any substance?

(A) 3.01×10^{22}
(C) 3.01×10^{23}
(B) 6.02×10^{22}
(D) 6.02×10^{23}

Lời giải chi tiết

Number of particles $= n \times N_A = 0.5 \times 6.02 \times 10^{23} = 3.01 \times 10^{23}$. **(C)**.

Bài tập luyện tập

Calculate the mass of 0.25 mol of calcium carbonate, $CaCO_3$ ($M_r = 100$).

Lời giải chi tiết

$m = n \times M_r = 0.25 \times 100 = 25$ g.

Bài tập luyện tập

Which statement about relative atomic mass, A_r, is correct?

(A) It is measured in grams.
(C) It compares atoms to oxygen-16.
(B) It has no units.
(D) It is always a whole number.

Lời giải chi tiết

A_r is a ratio of the average atomic mass to one-twelfth the mass of a carbon-12 atom, so it carries no units (and, because of isotopes, is not always a whole number — e.g. $A_r(\text{Cl}) = 35.5$). **(B)**.

3.2 Chemical formulae and balancing equations

3.2.1 Writing formulae from valencies

The formula of an ionic compound must be electrically neutral overall — the total positive charge from the cations must equal the total negative charge from the anions. This is most easily done with the **criss-cross method**: the number of each ion needed is the (numerical) charge of the *other* ion, cancelled to the simplest ratio.

Common ions and their charges

Charge $+1$	Na^+, K^+, Ag^+, NH_4^+, H^+
Charge $+2$	Mg^{2+}, Ca^{2+}, Cu^{2+}, Zn^{2+}, Fe^{2+}, Ba^{2+}
Charge $+3$	Al^{3+}, Fe^{3+}
Charge -1	Cl^-, OH^-, NO_3^-
Charge -2	O^{2-}, S^{2-}, SO_4^{2-}, CO_3^{2-}, SO_3^{2-}
Charge -3	PO_4^{3-}

Example: combine Al^{3+} with SO_4^{2-} — cross the charges (3 and 2) to give 2 aluminium ions for every 3 sulfate ions: $Al_2(SO_4)_3$.

VN **GIẢI THÍCH TIẾNG VIỆT**

Công thức hợp chất ion phải trung hoà về điện — tổng điện tích dương của cation bằng tổng điện tích âm của anion. Phương pháp "bắt chéo" (criss-cross): số lượng mỗi ion cần dùng bằng đúng trị số điện tích của ion kia (rồi rút gọn nếu có thể). Ví dụ Al^{3+} và SO_4^{2-} bắt chéo 3 và 2 → $Al_2(SO_4)_3$.

A balanced chemical equation must obey the **law of conservation of mass**: the same number of atoms of each element must appear on both sides. Coefficients (the numbers placed in front of formulae) are adjusted to balance the equation — the formulae themselves (subscripts) must *never* be changed, since that would describe a different substance entirely.

Systematic method for balancing equations

1. Write the word equation and the correct formula for every reactant and product (check valencies/ionic charges carefully).
2. Count the atoms of each element on both sides.
3. Balance one element at a time by placing whole-number coefficients in front of formulae — start with the element that appears in the fewest formulae, and leave free elements (such as O_2 or H_2) until last.
4. Re-count every element to confirm both sides now match.
5. Add the state symbols: (s) solid, (l) liquid, (g) gas, (aq) aqueous (dissolved in water).

Worked demonstration — balance the combustion of propane, $C_3H_8 + O_2 -> CO_2 + H_2O$:

- Balance C: 3 carbon atoms in C_3H_8 ⇒ put a 3 in front of CO_2.
- Balance H: 8 hydrogen atoms in C_3H_8 ⇒ put a 4 in front of H_2O (giving 8 H).
- Balance O last: right-hand side now has $3(2) + 4(1) = 10$ oxygen atoms ⇒ put a $\frac{10}{2} = 5$ in front of O_2.

$$C_3H_8(g) + 5O_2(g) -> 3CO_2(g) + 4H_2O(l)$$

Check: C: $3 = 3$; H: $8 = 8$; O: $5(2) = 10 = 3(2) + 4(1)$. Balanced.

VN **GIẢI THÍCH TIẾNG VIỆT**

Phương trình hoá học phải cân bằng theo định luật bảo toàn khối lượng — số nguyên tử mỗi nguyên tố phải bằng nhau ở hai vế. Chỉ được thay đổi **hệ số** (số đứng trước công thức), tuyệt đối không được sửa chỉ số trong công thức vì sẽ tạo ra chất khác. Mẹo: cân nguyên tố xuất hiện trong ít công thức nhất trước, để nguyên tố ở dạng đơn chất (như O_2, H_2) cân sau cùng.

Ký hiệu trạng thái: (s) rắn, (l) lỏng, (g) khí, (aq) tan trong nước (dung dịch).

State symbols

Symbol	Meaning
(s)	solid
(l)	liquid
(g)	gas
(aq)	aqueous — dissolved in water

3.2.2 Ionic equations (Supplement)

When two ionic compounds react in aqueous solution, many of the ions present do not actually take part in the reaction — these are called **spectator ions**. An **ionic equation** shows only the species that actually change, leaving out spectator ions.

Neutralisation of any strong acid by any strong alkali is always represented by the same ionic equation:

$$H^+(aq) + OH^-(aq) -> H_2O(l)$$

Precipitation reactions are written similarly — e.g. mixing barium chloride solution with sodium sulfate solution:

$$BaCl_2(aq) + Na_2SO_4(aq) -> BaSO_4(s) + 2NaCl(aq) \qquad \text{full equation}$$

$$Ba^{2+}(aq) + SO_4^{2-}(aq) -> BaSO_4(s) \qquad \text{ionic equation } (Na^+ \text{ and } Cl^- \text{ are spectator ions})$$

VN **GIẢI THÍCH TIẾNG VIỆT**

Phương trình ion chỉ viết các ion **thực sự tham gia phản ứng**, bỏ qua các ion khán giả (spectator ions) — những ion có mặt ở cả hai vế mà không thay đổi. Phản ứng trung hoà axit mạnh–bazơ mạnh luôn được viết là $H^+ + OH^- -> H_2O$, bất kể axit/bazơ cụ thể là gì.

(!) Lỗi thường gặp: Always balance the equation **before** reading off mole ratios from its coefficients. Using an unbalanced equation (e.g. treating $C_3H_8 + O_2 -> CO_2 + H_2O$ as if every coefficient were 1) will give a completely wrong mole ratio and therefore a wrong final answer, even if every other step of the calculation is correct.

Bài tập luyện tập

Balance the following equation for the combustion of butane:

$$C_4H_{10} + O_2 -> CO_2 + H_2O$$

Lời giải chi tiết

Balance C first (4 carbons $\Rightarrow$ 4 in front of CO_2), then H (10 hydrogens $\Rightarrow$ 5 in front of H_2O), then O last: right side has $4(2) + 5(1) = 13$ oxygen atoms, an odd number, so double every coefficient to clear it:

$$2C_4H_{10} + 13O_2 -> 8CO_2 + 10H_2O$$

Check: C: $8 = 8$; H: $20 = 20$; O: $13(2) = 26 = 8(2) + 10(1)$. Balanced.

Bài tập luyện tập

Balance the thermite reaction: $\text{Al} + \text{Fe}_2\text{O}_3 -> \text{Al}_2\text{O}_3 + \text{Fe}$.

Lời giải chi tiết

Balance Al: 2 in $\text{Al}_2\text{O}_3 \Rightarrow$ 2 in front of Al. Balance Fe: 2 in $\text{Fe}_2\text{O}_3 \Rightarrow$ 2 in front of Fe. Balance O: 3 on each side already.

$$2\text{Al} + \text{Fe}_2\text{O}_3 -> \text{Al}_2\text{O}_3 + 2\text{Fe}$$

Check: Al: $2 = 2$; Fe: $2 = 2$; O: $3 = 3$. Balanced.

Bài tập luyện tập

In the equation $\text{Mg(s)} + 2\text{HCl(aq)} -> \text{MgCl}_2\text{(aq)} + \text{H}_2\text{(g)}$, what does the state symbol (aq) indicate?

(A) a solid
(B) a pure liquid
(C) a gas
(D) dissolved in water

Lời giải chi tiết

(aq) means "aqueous" — the substance is dissolved in water. **(D)**.

Bài tập luyện tập

(Supplement) Write the full ionic equation for the precipitation reaction between silver nitrate solution and sodium chloride solution, given the full equation $\text{AgNO}_3\text{(aq)} + \text{NaCl(aq)} -> \text{AgCl(s)} + \text{NaNO}_3\text{(aq)}$.

Lời giải chi tiết

The spectator ions are Na^+ and NO_3^- (present unchanged on both sides). Ionic equation:

$$\text{Ag}^+\text{(aq)} + \text{Cl}^-\text{(aq)} -> \text{AgCl(s)}$$

Bài tập luyện tập

Use the criss-cross method to write the formula of aluminium oxide, from Al^{3+} and O^{2-}.

Lời giải chi tiết

Crossing charges 3 and 2 gives 2 aluminium ions for every 3 oxide ions: Al_2O_3.

Bài tập luyện tập

Write the formula of iron(III) sulfate, from Fe^{3+} and SO_4^{2-}.

Lời giải chi tiết

Crossing charges 3 and 2 gives 2 iron(III) ions for every 3 sulfate ions: $\text{Fe}_2(\text{SO}_4)_3$.

3.3 Empirical and molecular formulae

The **empirical formula** shows the simplest whole-number ratio of atoms of each element in a compound. The **molecular formula** shows the actual number of atoms of each element in one molecule — it is always a whole-number multiple of the empirical formula.

Finding the empirical formula from percentage composition

1. Assume a 100 g sample, so the % of each element equals its mass in grams.
2. Convert each mass to moles by dividing by its A_r.
3. Divide every mole value by the smallest one, to obtain the simplest whole-number ratio.

VN **GIẢI THÍCH TIẾNG VIỆT**

Công thức thực nghiệm là tỉ lệ nguyên đơn giản nhất giữa số nguyên tử các nguyên tố. Quy trình: giả sử mẫu 100 g → % khối lượng = khối lượng (g) → chia cho A_r ra số mol → chia tất cả cho giá trị nhỏ nhất để được tỉ lệ nguyên. Công thức phân tử = (công thức thực nghiệm)$_n$, với n tìm bằng cách lấy M_r phân tử chia cho khối lượng công thức thực nghiệm.

Ví dụ mẫu · Worked example

Empirical formula from percentage composition. A compound contains 40.0% carbon, 6.7% hydrogen and 53.3% oxygen by mass. Find its empirical formula.

	C	H	O
Mass (in 100 g)	40.0	6.7	53.3
$\div A_r$	$40.0/12 = 3.33$	$6.7/1 = 6.7$	$53.3/16 = 3.33$
÷ smallest (3.33)	1	2.0	1

Empirical formula = CH_2O (the repeating unit of carbohydrates such as glucose).

Ví dụ mẫu · Worked example

Empirical formula from combustion data. A 0.72 g sample of a hydrocarbon is burned completely in excess oxygen, producing 2.20 g of CO_2 and 1.08 g of H_2O. Find its empirical formula.

All the carbon in the sample ends up in CO_2, and all the hydrogen ends up in H_2O.

$$n(CO_2) = \frac{2.20}{44} = 0.05 \text{ mol} \Rightarrow n(C) = 0.05 \text{ mol} \Rightarrow m(C) = 0.05 \times 12 = 0.60 \text{ g}$$

$$n(H_2O) = \frac{1.08}{18} = 0.06 \text{ mol} \Rightarrow n(H) = 2 \times 0.06 = 0.12 \text{ mol} \Rightarrow m(H) = 0.12 \times 1 = 0.12 \text{ g}$$

Check: $m(C) + m(H) = 0.60 + 0.12 = 0.72$ g, equal to the sample mass, confirming the compound contains *only* carbon and hydrogen.

$$n(C) : n(H) = 0.05 : 0.12 = 1 : 2.4 = 5 : 12$$

Empirical formula = C_5H_{12} (pentane).

Ví dụ mẫu · Worked example

Molecular formula from empirical formula and M_r. A hydrocarbon has empirical formula CH_2 and relative molecular mass $M_r = 42$. Find its molecular formula.

Empirical formula mass of $CH_2 = 12 + 2 = 14$.

$$n = \frac{M_r(\text{molecular})}{M_r(\text{empirical})} = \frac{42}{14} = 3$$

Molecular formula $= (CH_2)_3 = C_3H_6$ (propene).

(!) Lỗi thường gặp: An empirical-formula ratio such as "1 : 2.4" must be scaled up to whole numbers (multiply throughout, here by 5, to give 5 : 12) — it must *never* be rounded to "1 : 2." Only round a ratio value when it is within about 0.05–0.1 of a whole number (e.g. 1.97 → 2, 3.02 → 3); a value like 2.4 or 2.5 signals that the whole set of ratios needs multiplying up.

Bài tập luyện tập

A compound contains 27.3% carbon and 72.7% oxygen by mass, and no other elements. Determine its empirical formula.

Lời giải chi tiết

$n(C) = 27.3/12 = 2.275$ mol; $n(O) = 72.7/16 = 4.544$ mol.
Divide by the smaller value (2.275): C $= 1$, O $= 4.544/2.275 \approx 2.0$.
Empirical formula $= CO_2$.

Bài tập luyện tập

A 0.30 g sample of a hydrocarbon burns completely to produce 0.88 g of CO_2 and 0.54 g of H_2O. Given that the relative molecular mass of the compound is 30, find its molecular formula.

Lời giải chi tiết

$n(CO_2) = 0.88/44 = 0.02$ mol $= n(C)$, so $m(C) = 0.02 \times 12 = 0.24$ g.
$n(H_2O) = 0.54/18 = 0.03$ mol $\Rightarrow n(H) = 0.06$ mol, so $m(H) = 0.06 \times 1 = 0.06$ g.
Check: $0.24 + 0.06 = 0.30$ g = sample mass, so no oxygen is present.
$n(C) : n(H) = 0.02 : 0.06 = 1 : 3 \Rightarrow$ empirical formula CH_3 (empirical mass $= 12 + 3 = 15$).
$n = M_r/15 = 30/15 = 2 \Rightarrow$ molecular formula $= C_2H_6$ (ethane).

Bài tập luyện tập

A compound has empirical formula CH_2 and $M_r = 84$. What is its molecular formula?

(A) C_4H_8
(B) C_5H_{10}
(C) C_6H_{12}
(D) C_7H_{14}

Lời giải chi tiết

Empirical formula mass $= 12 + 2 = 14$. $n = 84/14 = 6$. Molecular formula $= (CH_2)_6 = C_6H_{12}$. **(C)**.

Bài tập luyện tập

A 0.46 g sample of a compound containing only carbon, hydrogen and oxygen is burned completely, producing 0.88 g of CO_2 and 0.54 g of H_2O. Given $M_r = 46$, find the molecular formula. (Unlike a pure hydrocarbon, here the mass of oxygen must be found *by difference*.)

Lời giải chi tiết

$n(CO_2) = 0.88/44 = 0.02$ mol $= n(C)$, so $m(C) = 0.02 \times 12 = 0.24$ g.
$n(H_2O) = 0.54/18 = 0.03$ mol $\Rightarrow n(H) = 0.06$ mol, so $m(H) = 0.06 \times 1 = 0.06$ g.
Mass of C and H together $= 0.24 + 0.06 = 0.30$ g, which is *less* than the sample mass of 0.46 g, so the compound also contains oxygen: $m(O) = 0.46 - 0.30 = 0.16$ g, and $n(O) = 0.16/16 = 0.01$ mol.
$n(C) : n(H) : n(O) = 0.02 : 0.06 : 0.01 = 2 : 6 : 1 \Rightarrow$ empirical formula C_2H_6O (empirical mass $= 24 + 6 + 16 = 46$).
Since $M_r = 46$ equals the empirical formula mass, $n = 1$ and the molecular formula is also C_2H_6O (ethanol).

3.4 Calculations from equations — the mole-ratio method

A correctly balanced equation gives the exact **mole ratio** in which reactants combine and products form. Every "reacting quantities" question — whatever units it asks for — can be solved with the same four-step method.

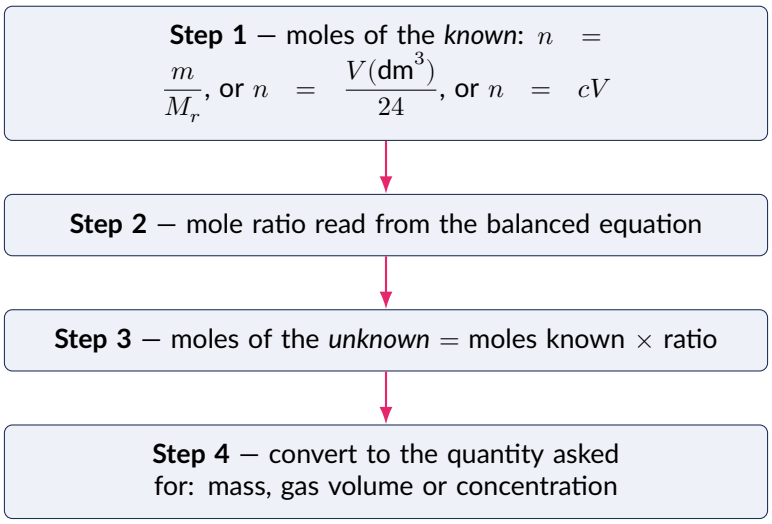
The 4-step mole-ratio method

Step 1. Convert the given quantity of the *known* substance into moles ($n = m/M_r$, or $n = V(\text{dm}^3)/24$ for a gas, or $n = c \times V$ for a solution).

Step 2. Read the mole ratio between the known and the unknown substance directly from the coefficients of the *balanced* equation.

Step 3. Multiply (or divide) by that ratio to find the moles of the *unknown* substance.

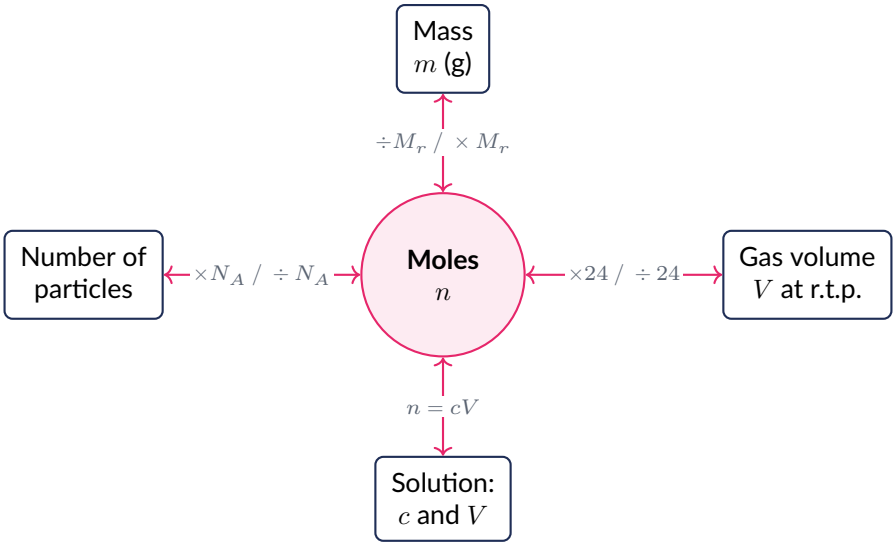
Step 4. Convert the moles of the unknown substance into whatever is asked for: mass ($m = n \times M_r$), gas volume ($V = n \times 24$ dm^3) or concentration ($c = n/V$).



VN GIẢI THÍCH TIẾNG VIỆT

Phương pháp 4 bước áp dụng cho **mọi** bài toán tính theo phương trình: (1) đổi dữ kiện đã cho của chất *đã biết* sang số mol; (2) đọc tỉ lệ mol từ hệ số phương trình *đã cân bằng*; (3) nhân/chia theo tỉ lệ đó để ra số mol chất *cần tìm*; (4) đổi số mol đó sang đơn vị đề bài yêu cầu (khối lượng, thể tích khí, hay nồng độ).

The diagram below summarises how the four quantities a mole can be converted into relate to each other — every arrow is reversible.



VN GIẢI THÍCH TIẾNG VIỆT

Số mol (n) là "trung tâm" để quy đổi qua lại giữa 4 đại lượng: khối lượng (chia/nhân M_r), số hạt (chia/nhân N_A), thể tích khí ở đktc phòng (chia/nhân 24), và nồng độ dung dịch ($n = cV$). Mọi mũi tên đều đi được hai chiều.

(!) Lỗi thường gặp: The mole ratio must always be read from a **balanced** equation, and it must match the substances actually asked about — not automatically 1:1. For example in $Fe_2O_3 + 3CO -> 2Fe + 3CO_2$, the ratio of Fe_2O_3 to Fe is $1 : 2$, not $1 : 1$; forgetting this is one of the most common calculation errors at IGCSE.

Bài tập luyện tập

Iron is extracted in the blast furnace by the reaction $Fe_2O_3 + 3CO -> 2Fe + 3CO_2$. Calculate the mass of Fe_2O_3 ($M_r = 160$) needed to produce 112 g of iron ($A_r = 56$).

Lời giải chi tiết

Step 1: $n(\text{Fe}) = \dfrac{112}{56} = 2$ mol.
Step 2: mole ratio Fe_2O_3 : Fe $= 1 : 2$.
Step 3: $n(Fe_2O_3) = 2 \div 2 = 1$ mol.
Step 4: $m(Fe_2O_3) = 1 \times 160 = 160$ g.

Bài tập luyện tập

Magnesium burns in oxygen: $2\text{Mg} + \text{O}_2 -> 2\text{MgO}$. Calculate the mass of oxygen needed to react completely with $12\,\text{g}$ of magnesium ($A_r = 24$).

Lời giải chi tiết

Step 1: $n(\text{Mg}) = \dfrac{12}{24} = 0.5$ mol.
Step 2: mole ratio $\text{O}_2 : \text{Mg} = 1 : 2$.
Step 3: $n(\text{O}_2) = 0.5 \div 2 = 0.25$ mol.
Step 4: $m(\text{O}_2) = 0.25 \times 32 = 8.0\,\text{g}$.

Bài tập luyện tập

Zinc reacts with excess dilute hydrochloric acid: $\text{Zn} + 2\text{HCl} -> \text{ZnCl}_2 + \text{H}_2$. Calculate the volume of hydrogen gas produced at r.t.p. from $13.0\,\text{g}$ of zinc ($A_r = 65$).

Lời giải chi tiết

Step 1: $n(\text{Zn}) = \dfrac{13.0}{65} = 0.2$ mol.
Step 2: mole ratio $\text{H}_2 : \text{Zn} = 1 : 1$.
Step 3: $n(\text{H}_2) = 0.2$ mol.
Step 4: $V(\text{H}_2) = 0.2 \times 24 = 4.8\,\text{dm}^3$.

3.5 The molar gas volume

At room temperature and pressure (r.t.p., taken as about $20\,^\circ$C and 1 atmosphere), **one mole of any gas occupies the same volume**: $24\,\text{dm}^3$ ($24000\,\text{cm}^3$) — regardless of what the gas is. This follows from **Avogadro's Law**: equal volumes of any gases, at the same temperature and pressure, contain equal numbers of moles (and hence molecules).

This is a remarkable result: the molar volume does *not* depend on the identity, size or mass of the gas particles — $24\,\text{dm}^3$ of hydrogen, of carbon dioxide, and of any other gas all contain exactly 6.02×10^{23} molecules at r.t.p. (Cambridge IGCSE uses r.t.p. throughout, rather than the standard temperature and pressure, s.t.p., sometimes used elsewhere — always use the value $24\,\text{dm}^3/\text{mol}$ unless a question states otherwise.)

In practice, the volume of a gas produced in a reaction is often measured directly with a gas syringe or by collecting it over water in an inverted measuring cylinder; the molar gas volume then allows that measured volume to be converted straight into moles, and from there into the moles (and mass) of any other substance in the reaction using the same 4-step method as Section 3.4.

$$n(\text{gas}) = \frac{V\ (\text{dm}^3)}{24} \qquad \Longleftrightarrow \qquad V\ (\text{dm}^3) = n \times 24$$

Because Avogadro's Law makes mole ratio = gas-volume ratio (at fixed T and P), volumes of gases in a reaction can be compared **directly** using the coefficients of the balanced equation — no need to convert to moles first when both quantities are gas volumes.

VN **GIẢI THÍCH TIẾNG VIỆT**

Ở điều kiện phòng (r.t.p.), 1 mol của **bất kỳ** chất khí nào cũng chiếm thể tích $24\,\text{dm}^3$ ($24\,000\ \text{cm}^3$) — không phụ thuộc bản chất khí. Theo định luật Avogadro, thể tích khí bằng

nhau (cùng nhiệt độ, áp suất) chứa số mol bằng nhau, nên có thể so sánh trực tiếp thể tích khí theo tỉ lệ hệ số phương trình mà không cần đổi qua số mol trước.

Ví dụ mẫu · Worked example

Gas volume ratio directly from the equation. Methane burns according to $CH_4(g) + 2O_2(g) -> CO_2(g) + 2H_2O(l)$. What volume of oxygen is required, and what volume of CO_2 is produced, when $6\,dm^3$ of methane is completely burned (all gas volumes measured at the same temperature and pressure)?

Gas volume ratio = mole ratio, read straight from the equation: $CH_4 : O_2 : CO_2 = 1 : 2 : 1$.

$$V(O_2) = 2 \times 6 = 12\,dm^3 \qquad V(CO_2) = 1 \times 6 = 6\,dm^3$$

(Water is not counted as a gas volume here since it condenses to liquid at r.t.p.)

(!) Lỗi thường gặp: A very common arithmetic slip is mixing up cm^3 and dm^3 (a factor-of-1000 error). Always convert volumes given in cm^3 into dm^3 *before* dividing by 24 (or convert moles $\times 24$ into dm^3, then $\times 1000$ if the final answer is required in cm^3). Write the unit at every step to catch this error immediately.

Bài tập luyện tập

The Haber process is represented by $N_2(g) + 3H_2(g) -> 2NH_3(g)$. What volume of hydrogen is needed to react completely with $20\,dm^3$ of nitrogen (same conditions)?

(A) $20\,dm^3$
(B) $40\,dm^3$
(C) $60\,dm^3$
(D) $80\,dm^3$

Lời giải chi tiết

Gas volume ratio $H_2 : N_2 = 3 : 1$. $V(H_2) = 3 \times 20 = 60\,dm^3$. **(C).**

Bài tập luyện tập

Using $N_2 + 3H_2 -> 2NH_3$, what volume of ammonia is produced from $30\,dm^3$ of nitrogen, assuming excess hydrogen and unchanged conditions?

Lời giải chi tiết

Gas volume ratio $NH_3 : N_2 = 2 : 1$. $V(NH_3) = 2 \times 30 = 60\,dm^3$.

Bài tập luyện tập

What volume does 0.1 mol of any gas occupy at r.t.p.?

(A) $0.24\,dm^3$
(B) $2.4\,dm^3$
(C) $24\,dm^3$
(D) $240\,dm^3$

Lời giải chi tiết

$V = n \times 24 = 0.1 \times 24 = 2.4\,\text{dm}^3$. **(B).**

Bài tập luyện tập

Avogadro's Law states that equal volumes of gases, measured at the same temperature and pressure, contain equal numbers of:

(A) atoms
(B) moles (particles)
(C) grams
(D) electrons

Lời giải chi tiết

Avogadro's Law refers to equal numbers of *moles* (i.e. molecules/particles), not atoms, mass or electrons directly — this is exactly why gas-volume ratios equal mole ratios. **(B).**

Bài tập luyện tập

Ethane burns according to $2C_2H_6(g) + 7O_2(g) -> 4CO_2(g) + 6H_2O(l)$. What volume of CO_2 is produced when $10\,\text{dm}^3$ of ethane is completely burned in excess oxygen (all gas volumes at the same temperature and pressure)?

Lời giải chi tiết

Gas volume ratio $CO_2 : C_2H_6 = 4 : 2 = 2 : 1$. $V(CO_2) = 2 \times 10 = 20\,\text{dm}^3$.

3.6 Limiting reactants and percentage yield

When two reactants are mixed in amounts that do not exactly match the mole ratio in the equation, one of them will run out first. This reactant is called the **limiting reactant** (or limiting reagent) — it is entirely used up and controls the maximum possible amount of product; the other reactant is said to be **in excess**. In industry, the more expensive or harder-to-obtain reactant is often deliberately made the limiting one, with a cheaper reactant supplied in excess to help push the reaction as far as possible towards completion.

Identifying the limiting reactant

For each reactant, calculate the moles *available*. Then, using the mole ratio from the balanced equation, calculate how many moles of one reactant would be *needed* to react exactly with the moles available of the other. Compare needed with available: whichever reactant would run out first (i.e. less is available than is needed) is the limiting reactant, and it is this reactant's moles that must be used in Step 1 of any subsequent product calculation.

VN **GIẢI THÍCH TIẾNG VIỆT**

Khi trộn hai chất phản ứng không đúng theo tỉ lệ mol của phương trình, chất nào hết trước gọi là **chất phản ứng hết** (limiting reactant) — chất này quyết định lượng sản phẩm tối đa; chất còn lại gọi là **dư**. Cách xác định: tính số mol có sẵn của mỗi chất, tính số mol *cần* theo tỉ lệ phương trình, so sánh — chất nào không đủ so với lượng cần là chất hết trước.

Ví dụ mẫu · Worked example

Limiting reactant and gas volume. $1.2\,\text{g}$ of magnesium ribbon is added to $100\,\text{cm}^3$ of $2.0\,\text{mol/dm}^3$ hydrochloric acid: $\text{Mg} + 2\text{HCl} -> \text{MgCl}_2 + \text{H}_2$.

(a) $n(\text{Mg}) = \dfrac{1.2}{24} = 0.05$ mol.

(b) $n(\text{HCl})$ available $= 2.0 \times \dfrac{100}{1000} = 0.20$ mol; $n(\text{HCl})$ *needed* for 0.05 mol Mg (ratio $2 : 1$) $= 2 \times 0.05 = 0.10$ mol. Since $0.20 > 0.10$, HCl is in **excess** and Mg is the limiting reactant.

(c) $n(\text{H}_2)$ produced $= n(\text{Mg})$ (ratio $1 : 1$) $= 0.05$ mol. $V(\text{H}_2)$ at r.t.p. $= 0.05 \times 24 = 1.2\,\text{dm}^3$ ($1200\,\text{cm}^3$).

Even when the limiting reactant is correctly identified, the mass of product actually obtained in an experiment (the **actual yield**) is almost always less than the maximum mass calculated from the equation (the **theoretical yield**), because of incomplete reactions, side reactions, or losses during filtration, transfer and purification.

$$\%\ \text{yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$

VN **GIẢI THÍCH TIẾNG VIỆT**

Hiệu suất phần trăm = (khối lượng thực tế thu được ÷ khối lượng lý thuyết tối đa) $\times 100\%$. Khối lượng lý thuyết luôn tính từ chất phản ứng hết (limiting reactant), không phải chất dư.

Ví dụ mẫu · Worked example

Percentage yield. A student reacts $4.0\,\text{g}$ of calcium carbonate with excess hydrochloric acid: $\text{CaCO}_3 + 2\text{HCl} -> \text{CaCl}_2 + \text{H}_2\text{O} + \text{CO}_2$. The actual mass of CaCl_2 obtained is $3.33\,\text{g}$. Calculate the percentage yield.

$n(\text{CaCO}_3) = \dfrac{4.0}{100} = 0.04$ mol (ratio $1 : 1$ with CaCl_2, $M_r = 111$).

Theoretical mass of $\text{CaCl}_2 = 0.04 \times 111 = 4.44\,\text{g}$.

$$\%\ \text{yield} = \frac{3.33}{4.44} \times 100 = 75\%$$

(!) Lỗi thường gặp: Percentage yield can never legitimately exceed 100% for a correctly-run experiment (losses always occur; nothing is created from nothing). If a % yield calculation gives an answer above 100%, re-check the mole ratio and the M_r values used — a common cause is using the wrong reactant's moles (the excess reactant instead of the limiting one) as the basis for the theoretical yield.

Bài tập luyện tập

$5.4\,\text{g}$ of aluminium is reacted with $400\,\text{cm}^3$ of $1.0\,\text{mol/dm}^3$ hydrochloric acid: $2\text{Al} + 6\text{HCl} -> 2\text{AlCl}_3 + 3\text{H}_2$ (A_r: Al $= 27$). Identify the limiting reactant and calculate the maximum volume of hydrogen gas produced at r.t.p.

Lời giải chi tiết

$n(\text{Al}) = \dfrac{5.4}{27} = 0.2$ mol; $n(\text{HCl})$ available $= 1.0 \times 0.400 = 0.4$ mol.
HCl needed for 0.2 mol Al (ratio $6:2 = 3:1$) $= 0.2 \times 3 = 0.6$ mol > 0.4 mol available $\Rightarrow$ **HCl is the limiting reactant**.
$n(\text{H}_2)$ (ratio $\text{H}_2 : \text{HCl} = 3:6 = 1:2$) $= 0.4 \div 2 = 0.2$ mol.
$V(\text{H}_2) = 0.2 \times 24 = 4.8\,\text{dm}^3$ (4800 cm^3).

Bài tập luyện tập

4.8 g of magnesium ($A_r = 24$) is burned with 2.4 g of oxygen ($A_r = 16$): $2\text{Mg} + \text{O}_2 -> 2\text{MgO}$. Identify the limiting reactant and calculate the mass of magnesium oxide ($M_r = 40$) formed.

Lời giải chi tiết

$n(\text{Mg}) = \dfrac{4.8}{24} = 0.2$ mol; $n(\text{O}_2) = \dfrac{2.4}{32} = 0.075$ mol.
O_2 needed for 0.2 mol Mg (ratio $\text{Mg} : \text{O}_2 = 2:1$) $= 0.2 \div 2 = 0.1$ mol > 0.075 mol available $\Rightarrow$ O_2 **is the limiting reactant**.
$n(\text{MgO})$ (ratio $\text{MgO} : \text{O}_2 = 2:1$) $= 2 \times 0.075 = 0.15$ mol.
$m(\text{MgO}) = 0.15 \times 40 = 6.0$ g.

Bài tập luyện tập

10.6 g of sodium carbonate ($M_r = 106$) reacts with excess hydrochloric acid: $\text{Na}_2\text{CO}_3 + 2\text{HCl} -> 2\text{NaCl} + \text{H}_2\text{O} + \text{CO}_2$. If 9.36 g of sodium chloride ($M_r = 58.5$) is actually obtained, calculate the percentage yield.

Lời giải chi tiết

$n(\text{Na}_2\text{CO}_3) = \dfrac{10.6}{106} = 0.1$ mol. Ratio $\text{NaCl} : \text{Na}_2\text{CO}_3 = 2:1 \Rightarrow n(\text{NaCl}) = 0.2$ mol.
Theoretical mass $= 0.2 \times 58.5 = 11.7$ g.

$$\%\ \text{yield} = \frac{9.36}{11.7} \times 100 = 80\%$$

Bài tập luyện tập

A $3.0\,\text{dm}^3$ sample of methane is mixed with $3.0\,\text{dm}^3$ of oxygen and ignited: $\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) -> \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l})$ (all volumes at the same temperature and pressure). Identify the limiting reactant and find the volume of CO_2 produced.

Lời giải chi tiết

O_2 needed to burn all $3.0\,\text{dm}^3$ CH_4 (ratio $\text{O}_2 : \text{CH}_4 = 2:1$) $= 2 \times 3.0 = 6.0\,\text{dm}^3$, but only $3.0\,\text{dm}^3$ O_2 is available $\Rightarrow$ O_2 **is the limiting reactant**.
CH_4 that actually reacts (ratio $\text{CH}_4 : \text{O}_2 = 1:2$) $= 3.0 \div 2 = 1.5\,\text{dm}^3$.
$V(\text{CO}_2)$ (ratio $\text{CO}_2 : \text{CH}_4 = 1:1$) $= 1.5\,\text{dm}^3$.

Bài tập luyện tập

The Haber process, $N_2 + 3H_2 -> 2NH_3$, is carried out starting from 56 g of nitrogen ($M_r = 28$) with excess hydrogen, and gives an 85% yield of ammonia ($M_r = 17$). Calculate the actual mass of ammonia produced.

Lời giải chi tiết

$n(N_2) = \dfrac{56}{28} = 2$ mol. Ratio $NH_3 : N_2 = 2:1 \Rightarrow n(NH_3)$ theoretical $= 2 \times 2 = 4$ mol.
Theoretical mass $= 4 \times 17 = 68$ g.
Actual mass $= 68 \times \dfrac{85}{100} = 57.8$ g.

3.7 Concentration of solutions and titration calculations

The **concentration** of a solution is the amount of solute dissolved per unit volume of solution, and can be expressed either in mol/dm^3 or in g/dm^3.

$$c\ (\text{mol/dm}^3) = \frac{n\ (\text{mol})}{V\ (\text{dm}^3)} \qquad \Longleftrightarrow \qquad n = c \times V$$

$$c\ (\text{g/dm}^3) = \frac{m\ (\text{g})}{V\ (\text{dm}^3)} \qquad \Longleftrightarrow \qquad c\ (\text{g/dm}^3) = c\ (\text{mol/dm}^3) \times M_r$$

Remember 1 dm$^3 = 1000$ cm$^3 = 1$ litre.

For example, a solution of sodium hydroxide with $c = 0.20$ mol/dm^3 ($M_r(\text{NaOH}) = 40$) has $c\ (\text{g/dm}^3) = 0.20 \times 40 = 8.0$ g/dm^3; the two ways of stating concentration always describe the same solution.

VN **GIẢI THÍCH TIẾNG VIỆT**
Nồng độ mol = số mol ÷ thể tích (dm^3). Nồng độ g/dm^3 = khối lượng (g) ÷ thể tích (dm^3), và có thể đổi qua nồng độ mol bằng cách chia/nhân cho M_r. Luôn nhớ 1 dm$^3 = 1000$ cm$^3 = 1$ lít — đổi cm^3 →dm^3 bằng cách chia cho 1000.

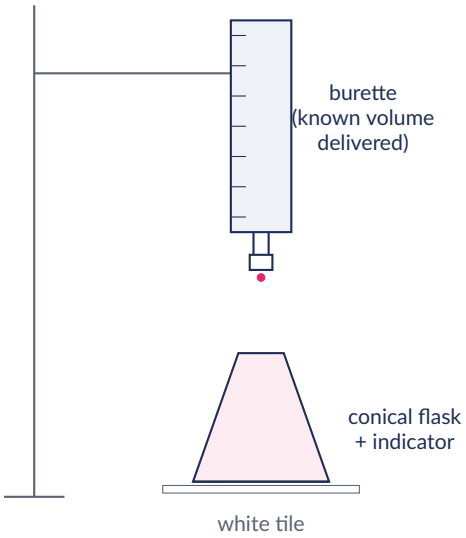
3.7.1 Titration calculations

In an acid–base titration, a known volume of one solution (measured accurately by pipette) is placed in a conical flask with a few drops of indicator, and the other solution is added gradually from a burette until the indicator just changes colour (the **end-point**). The volume of solution added from the burette is called the **titre**.

- The burette and pipette are always rinsed with a little of the solution they are about to measure (not with water alone), so that the solution is not diluted.
- The titration is repeated until at least two titres agree closely ("concordant results," typically within 0.10 cm^3 of each other); these concordant titres are averaged before being used in a calculation.
- The initial and final burette readings are both recorded; the titre is the *difference* between them, not the final reading alone.

VN **GIẢI THÍCH TIẾNG VIỆT**
Burette và pipette luôn được tráng bằng chính dung dịch sắp đong (không chỉ nước cất) để tránh pha loãng. Chuẩn độ được lặp lại đến khi có ít nhất 2 lần thể tích chuẩn độ (titre) gần

nhau (thường trong khoảng $0.10\,\text{cm}^3$) — gọi là kết quả phù hợp (concordant), sau đó lấy trung bình các lần này để tính toán. Titre = số đọc cuối − số đọc đầu trên burette.



Method for titration calculations

Step 1. From the solution whose concentration *and* volume are both known, calculate its moles: $n = cV$ (convert volume to dm^3 first).

Step 2. Read the mole ratio between the two reacting substances from the balanced equation.

Step 3. Use the ratio to find the moles of the other substance.

Step 4. Divide by its volume (in dm^3) to obtain its concentration: $c = n/V$.

VN **GIẢI THÍCH TIẾNG VIỆT**

Chuẩn độ (titration): nhỏ dần dung dịch từ burette vào dung dịch trong bình tam giác có chỉ thị màu, đến khi đổi màu (điểm cuối). Phương pháp tính: (1) tính số mol của dung dịch đã biết *cả* nồng độ và thể tích; (2) đọc tỉ lệ mol từ phương trình cân bằng; (3) suy ra số mol chất còn lại; (4) chia cho thể tích (dm^3) để ra nồng độ.

Ví dụ mẫu · Worked example

Titration — finding the concentration of an acid. $25.0\,\text{cm}^3$ of $0.200\,\text{mol/dm}^3$ sodium hydroxide solution is exactly neutralised by $20.0\,\text{cm}^3$ of hydrochloric acid: $\text{NaOH} + \text{HCl} -> \text{NaCl} + \text{H}_2\text{O}$. Calculate the concentration of the HCl.

Step 1: $n(\text{NaOH}) = 0.200 \times \dfrac{25.0}{1000} = 0.00500$ mol.

Step 2: mole ratio HCl : NaOH $= 1 : 1$.

Step 3: $n(\text{HCl}) = 0.00500$ mol.

Step 4: $c(\text{HCl}) = \dfrac{0.00500}{20.0/1000} = \dfrac{0.00500}{0.0200} = 0.250\,\text{mol/dm}^3$.

Ví dụ mẫu · Worked example

Titration with a diprotic acid. $25.0\,\text{cm}^3$ of sodium hydroxide solution requires $15.0\,\text{cm}^3$ of $0.100\,\text{mol/dm}^3$ sulfuric acid for complete neutralisation: $2\text{NaOH} + \text{H}_2\text{SO}_4 -> \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O}$. Calculate the concentration of the NaOH.

Step 1: $n(\text{H}_2\text{SO}_4) = 0.100 \times \dfrac{15.0}{1000} = 0.00150$ mol.

Step 2: mole ratio NaOH : $\text{H}_2\text{SO}_4 = 2 : 1$ (sulfuric acid is diprotic — each mole supplies 2 mol H^+).

Step 3: $n(\text{NaOH}) = 2 \times 0.00150 = 0.00300$ mol.

Step 4: $c(\text{NaOH}) = \dfrac{0.00300}{25.0/1000} = \dfrac{0.00300}{0.0250} = 0.120\,\text{mol/dm}^3$.

(!) Lỗi thường gặp: Never assume the mole ratio in a titration is automatically $1 : 1$. Diprotic acids such as H_2SO_4 and bases such as Ca(OH)_2 react in ratios like $2 : 1$ or $1 : 2$ — always read the ratio from the balanced equation for that specific reaction (Step 2), not from habit.

Bài tập luyện tập

A solution of sodium hydroxide has a concentration of $8.0\,\text{g/dm}^3$. Calculate its concentration in mol/dm^3 ($M_r(\text{NaOH}) = 40$).

Lời giải chi tiết

$c\ (\text{mol/dm}^3) = \dfrac{c\ (\text{g/dm}^3)}{M_r} = \dfrac{8.0}{40} = 0.20\,\text{mol/dm}^3$.

Bài tập luyện tập

$20.0\,\text{cm}^3$ of $0.150\,\text{mol/dm}^3$ sulfuric acid exactly neutralises $30.0\,\text{cm}^3$ of potassium hydroxide solution: $2\text{KOH} + \text{H}_2\text{SO}_4 -> \text{K}_2\text{SO}_4 + 2\text{H}_2\text{O}$. Calculate the concentration of the KOH.

Lời giải chi tiết

$n(\text{H}_2\text{SO}_4) = 0.150 \times \dfrac{20.0}{1000} = 0.00300$ mol.

Mole ratio KOH : $\text{H}_2\text{SO}_4 = 2 : 1 \Rightarrow n(\text{KOH}) = 2 \times 0.00300 = 0.00600$ mol.

$c(\text{KOH}) = \dfrac{0.00600}{30.0/1000} = \dfrac{0.00600}{0.0300} = 0.200\,\text{mol/dm}^3$.

Bài tập luyện tập

In a titration, $21.40\,\text{cm}^3$ of $0.0500\,\text{mol/dm}^3$ sodium hydroxide exactly neutralises $25.00\,\text{cm}^3$ of hydrochloric acid: $\text{NaOH} + \text{HCl} -> \text{NaCl} + \text{H}_2\text{O}$. Calculate the concentration of the HCl in (a) mol/dm^3 and (b) g/dm^3 ($M_r(\text{HCl}) = 36.5$).

Lời giải chi tiết

$n(\text{NaOH}) = 0.0500 \times \dfrac{21.40}{1000} = 0.0500 \times 0.02140 = 1.070 \times 10^{-3}$ mol.

Mole ratio $1 : 1 \Rightarrow n(\text{HCl}) = 1.070 \times 10^{-3}$ mol.

(a) $c(\text{HCl}) = \dfrac{1.070 \times 10^{-3}}{25.00/1000} = \dfrac{1.070 \times 10^{-3}}{0.02500} = 0.0428\,\text{mol/dm}^3$.
(b) $c(\text{g/dm}^3) = 0.0428 \times 36.5 = 1.56\,\text{g/dm}^3$ (3 s.f.).

3.8 Percentage purity, water of crystallisation and dilution

Samples of chemicals used in industry or the laboratory are rarely 100% pure — they contain impurities that do not react (or react differently, or do not react at all). Impurities may come from the raw material itself (e.g. limestone quarried from rock always contains some clay and sand alongside $CaCO_3$), from side reactions, or from incomplete purification. The **percentage purity** tells us what fraction of a sample is actually the substance of interest.

$$\%\ \text{purity} = \frac{\text{mass of pure substance}}{\text{mass of impure sample}} \times 100$$

VN **GIẢI THÍCH TIẾNG VIỆT**
Độ tinh khiết phần trăm = (khối lượng chất tinh khiết ÷ khối lượng mẫu không tinh khiết) $\times 100\%$. Khối lượng chất tinh khiết thường phải tính ra từ dữ kiện phản ứng (ví dụ từ thể tích khí sinh ra) bằng phương pháp 4 bước, chứ không cho trực tiếp.

Ví dụ mẫu · Worked example

Percentage purity. A $12.5\,\text{g}$ sample of impure calcium carbonate is reacted with excess dilute hydrochloric acid, producing $2.64\,\text{g}$ of carbon dioxide gas: $CaCO_3 + 2HCl -> CaCl_2 + H_2O + CO_2$. Calculate the percentage purity of the sample.

$n(CO_2) = \dfrac{2.64}{44} = 0.06\ \text{mol} = n(CaCO_3)$ reacted (ratio $1:1$).
Mass of pure $CaCO_3 = 0.06 \times 100 = 6.0\,\text{g}$.

$$\%\ \text{purity} = \frac{6.0}{12.5} \times 100 = 48\%$$

3.8.1 Water of crystallisation (Supplement)

Many ionic solids form **hydrated crystals**, in which a fixed number of water molecules (x) is chemically bonded into the crystal lattice for every formula unit of the salt, written $X.xH_2O$. Heating a hydrated salt gently drives off this **water of crystallisation**, leaving the **anhydrous** salt. The value of x can be found from the mass lost on heating.

Finding x in $X.xH_2O$

1. Mass of water lost = mass of hydrated salt − mass of anhydrous salt (after heating to constant mass).
2. Moles of anhydrous salt = (mass of anhydrous salt) / M_r(anhydrous salt).
3. Moles of water lost = (mass of water) / 18.
4. $x = \dfrac{\text{moles of water}}{\text{moles of anhydrous salt}}$, rounded to the nearest whole number.

VN **GIẢI THÍCH TIẾNG VIỆT**

Nhiều muối ion kết tinh ngậm một số phân tử nước cố định (x) trong mạng tinh thể, viết X.xH_2O. Khi nung, nước kết tinh bay hơi, còn lại muối khan (anhydrous). Tìm x: khối lượng nước mất = khối lượng muối ngậm nước − khối lượng muối khan; đổi cả khối lượng muối khan và khối lượng nước sang số mol; x = tỉ lệ mol nước / mol muối khan.

Ví dụ mẫu · Worked example

Water of crystallisation (Supplement). $12.5\,\text{g}$ of hydrated copper(II) sulfate, $CuSO_4.xH_2O$, is heated to constant mass, leaving $8.0\,\text{g}$ of anhydrous copper(II) sulfate, $CuSO_4$ ($M_r = 160$). Find x.

Mass of water lost $= 12.5 - 8.0 = 4.5\,\text{g}$.

$n(CuSO_4) = \dfrac{8.0}{160} = 0.05$ mol.

$n(H_2O) = \dfrac{4.5}{18} = 0.25$ mol.

$$x = \frac{n(H_2O)}{n(CuSO_4)} = \frac{0.25}{0.05} = 5$$

So the formula is $CuSO_4.5H_2O$ (hydrated copper(II) sulfate, "blue vitriol").

3.8.2 Dilution of solutions (Supplement)

A solution of lower concentration can be made from a stock solution by adding water. Because adding water does not change the number of moles of solute present, the moles before and after dilution are equal:

$$c_1 V_1 = c_2 V_2$$

where c_1, V_1 are the concentration and volume *before* dilution and c_2, V_2 are the concentration and volume *after* dilution (any consistent volume unit may be used, since it cancels in the ratio).

VN **GIẢI THÍCH TIẾNG VIỆT**

Khi pha loãng, số mol chất tan không đổi (chỉ thêm nước), nên $c_1 V_1 = c_2 V_2$ — với c_1, V_1 là nồng độ/thể tích *trước* khi pha loãng và c_2, V_2 là nồng độ/thể tích *sau* khi pha loãng. Thể tích nước cần thêm = $V_2 - V_1$.

Ví dụ mẫu · Worked example

Dilution (Supplement). What volume of water must be added to $50.0\,\text{cm}^3$ of $2.00\,\text{mol/dm}^3$ hydrochloric acid to obtain a solution of concentration $0.500\,\text{mol/dm}^3$?

$$c_1 V_1 = c_2 V_2 \;\Rightarrow\; 2.00 \times 50.0 = 0.500 \times V_2 \;\Rightarrow\; V_2 = \frac{100}{0.500} = 200\,\text{cm}^3$$

Volume of water added $= V_2 - V_1 = 200 - 50.0 = 150\,\text{cm}^3$.

(!) Lỗi thường gặp: When converting volumes between cm^3 and dm^3 in purity, titration or dilution questions, always divide cm^3 by 1000 to get dm^3 *before* using $n = cV$ — plugging a cm^3 value directly into c (mol/dm^3) $\times\, V$ gives an answer 1000 times too large. Writing the unit next to every number is the simplest way to avoid this.

Bài tập luyện tập

A $9.75\,\text{g}$ sample of impure sodium chloride is dissolved in water and reacted with excess silver nitrate solution, producing $14.35\,\text{g}$ of silver chloride precipitate: $\text{NaCl} + \text{AgNO}_3 -> \text{AgCl} + \text{NaNO}_3$ ($M_r(\text{AgCl}) = 143.5$, $M_r(\text{NaCl}) = 58.5$). Calculate the percentage purity of the sodium chloride sample.

Lời giải chi tiết

$n(\text{AgCl}) = \dfrac{14.35}{143.5} = 0.1$ mol $= n(\text{NaCl})$ reacted (ratio $1:1$).
Mass of pure NaCl $= 0.1 \times 58.5 = 5.85\,\text{g}$.

$$\%\ \text{purity} = \frac{5.85}{9.75} \times 100 = 60\%$$

Bài tập luyện tập

A $20.0\,\text{g}$ sample of impure iron contains $17.0\,\text{g}$ of pure iron. What is its percentage purity?

(A) 75%
(B) 80%
(C) 85%
(D) 90%

Lời giải chi tiết

$\%\ \text{purity} = \dfrac{17.0}{20.0} \times 100 = 85\%$. **(C)**.

Bài tập luyện tập

(Supplement) What volume of water must be added to $25.0\,\text{cm}^3$ of $4.0\,\text{mol/dm}^3$ solution to dilute it to $0.50\,\text{mol/dm}^3$?

Lời giải chi tiết

$c_1V_1 = c_2V_2 \Rightarrow 4.0 \times 25.0 = 0.50 \times V_2 \Rightarrow V_2 = \dfrac{100}{0.50} = 200\,\text{cm}^3$.
Volume of water added $= 200 - 25.0 = 175\,\text{cm}^3$.

Bài tập luyện tập

(Supplement) $6.15\,\text{g}$ of hydrated magnesium sulfate, $\text{MgSO}_4.x\text{H}_2\text{O}$, is heated to constant mass, leaving $3.00\,\text{g}$ of anhydrous MgSO_4 ($M_r = 120$). Find x.

Lời giải chi tiết

Mass of water lost $= 6.15 - 3.00 = 3.15\,\text{g}$.
$n(\text{MgSO}_4) = \dfrac{3.00}{120} = 0.025$ mol.
$n(\text{H}_2\text{O}) = \dfrac{3.15}{18} = 0.175$ mol.
$x = \dfrac{0.175}{0.025} = 7$. Formula: $\text{MgSO}_4.7\text{H}_2\text{O}$ (Epsom salt).

Bài tập luyện tập

A 50.0 cm^3 sample of 0.400 mol/dm^3 sodium hydroxide solution is prepared by diluting a stock solution of concentration 2.00 mol/dm^3. What volume of the stock solution, and what volume of water, are needed?

Lời giải chi tiết

$c_1V_1 = c_2V_2 \Rightarrow 2.00 \times V_1 = 0.400 \times 50.0 \Rightarrow V_1 = \dfrac{20.0}{2.00} = 10.0$ cm^3 of stock solution.
Volume of water added $= 50.0 - 10.0 = 40.0$ cm^3.

Ôn tập nhanh

- $n = m/M_r$; $n = V(\text{dm}^3)/24$ cho khí ở r.t.p.; $n = cV$ cho dung dịch; số hạt $= n \times N_A$.
- Công thức thực nghiệm: % khối lượng → mol (chia A_r) → chia cho số nhỏ nhất; nếu tỉ lệ lẻ, nhân lên số nguyên. Công thức phân tử $=$ (thực nghiệm)$_n$ với $n = M_r$(phân tử)$/M_r$(thực nghiệm).
- Luôn cân bằng phương trình **trước**, rồi mới đọc tỉ lệ mol từ hệ số — áp dụng đúng 4 bước cho mọi bài toán khối lượng/thể tích/nồng độ.
- Chất phản ứng hết quyết định lượng sản phẩm tối đa; hiệu suất % luôn $\leq 100\%$; độ tinh khiết % tính trên khối lượng mẫu không tinh khiết.
- Chuẩn độ: tỉ lệ mol axit–bazơ không phải luôn $1:1$ — đặc biệt với axit/bazơ hai lần như H_2SO_4, $Ca(OH)_2$.
- Luôn đổi cm^3 →dm^3 (chia 1000) trước khi dùng công thức nồng độ.
- Công thức ngậm nước: $x =$ (mol nước mất đi) ÷ (mol muối khan còn lại sau khi nung).
- Pha loãng: $c_1V_1 = c_2V_2$ (số mol chất tan không đổi khi thêm nước).

Electrochemistry

Mục tiêu Unit: Nguyên lý điện phân (cathode khử, anode oxi hoá, ion chỉ di chuyển tự do khi nóng chảy hoặc hoà tan trong nước); điện phân hợp chất ion nóng chảy ($PbBr_2$, $PbCl_2$, $ZnCl_2$...) và dung dịch nước (nước muối đặc, axit sulfuric loãng, đồng(II) sulfat với điện cực trơ và điện cực đồng, axit hydrochloric); quy tắc phóng điện ưu tiên cho cation và anion; ba ứng dụng công nghiệp cốt lõi — tách nhôm bằng điện phân, tinh luyện đồng, và mạ điện; và (phần mở rộng) pin điện hoá đơn giản dựa trên dãy hoạt động hoá học.

4.1 Principles of electrolysis

Electrolysis is the decomposition (breaking down) of an ionic compound, when molten or dissolved in water, by passing a direct electric current (d.c.) through it. The compound being decomposed is called the **electrolyte**. Ionic compounds conduct electricity — and can only be electrolysed — when their ions are free to move: that is, when *molten* (liquid) or *dissolved in water* (aqueous). In the solid state, the ions are locked into fixed positions in a rigid lattice, held there by strong electrostatic attractions; they can only vibrate about those fixed positions and cannot travel through the structure to carry charge. A solid ionic compound therefore neither conducts electricity nor can be electrolysed.

Two electrodes, usually made of an unreactive (**inert**) material such as graphite or platinum unless stated otherwise, dip into the electrolyte and are connected to a d.c. supply.

- At the **cathode** (the negative electrode), positive ions (**cations**) migrate towards the electrode, *gain* electrons, and are **reduced**.
- At the **anode** (the positive electrode), negative ions (**anions**) migrate towards the electrode, *lose* electrons, and are **oxidised**.

This pattern — reduction at the cathode, oxidation at the anode — holds for *every* electrolytic cell, regardless of the electrolyte. The words “oxidation” and “reduction” here refer purely to electron transfer (gain of electrons = reduction; loss of electrons = oxidation, remembered by the mnemonic OIL RIG), not necessarily to reactions involving oxygen.

Why the physical state matters:

State of the ionic compound	Are the ions free to move?	Conducts electricity / can be electrolysed?
Solid	No — ions vibrate about fixed lattice positions	No
Molten (liquid)	Yes — the giant ionic lattice has broken down	Yes
Dissolved in water (aqueous)	Yes — ions are separated and surrounded by water molecules	Yes

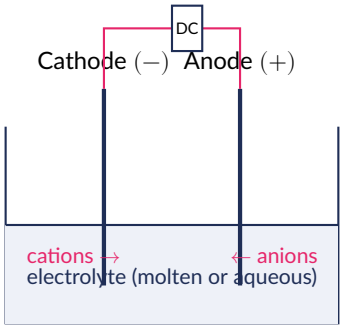


Figure 1. Simple electrolysis cell: cations migrate to the cathode and are reduced; anions migrate to the anode and are oxidised.

VN **GIẢI THÍCH TIẾNG VIỆT**

Điện phân là quá trình phân huỷ hợp chất ion bằng dòng điện một chiều, chỉ xảy ra khi hợp chất **nóng chảy** hoặc **hoà tan trong nước** (khi đó ion mới di chuyển tự do được — ở thể rắn, ion bị khoá cứng trong mạng tinh thể nên không dẫn điện). Cực **âm (cathode)**: cation di chuyển tới, nhận electron → bị **khử**. Cực **dương (anode)**: anion di chuyển tới, nhường electron → bị **oxi hoá**. Quy luật này luôn đúng với mọi chất điện phân, không phụ thuộc vào bản chất của nó.

4.1.1 Oxidation and reduction as electron transfer

Khái niệm cốt lõi

At every electrode, the fundamental process is the transfer of electrons between an ion (or, sometimes, a reactive electrode) and the external circuit:

- **Reduction** = gain of electrons: $M^{n+} + ne^- -> M$.
- **Oxidation** = loss of electrons: $X^{n-} -> X + ne^-$.

Since the cathode is where cations arrive and gain electrons, reduction *always* happens at the cathode; since the anode is where anions arrive and lose electrons, oxidation *always* happens at the anode — whatever ions are actually present. Electrons flow through the external wire and d.c. supply from the anode to the cathode, driven by the supply, while current (conventional) flows the opposite way.

VN **GIẢI THÍCH TIẾNG VIỆT**

Khử là quá trình **nhận electron**; oxi hoá là quá trình **nhường electron** (nhớ bằng OIL RIG: Oxidation Is Loss, Reduction Is Gain). Vì cation luôn di chuyển tới cathode để nhận electron, nên **khử luôn xảy ra ở cathode**; vì anion luôn di chuyển tới anode để nhường electron, nên **oxi hoá luôn xảy ra ở anode** — bất kể chất điện phân là gì.

4.1.2 Apparatus and testing the gaseous products

A **Hofmann voltameter** — a cell fitted with two vertical, graduated glass limbs, one above each electrode — allows the gases produced during electrolysis to be collected separately and their volumes compared; a tap at the top of each limb allows a sample of gas to be withdrawn for testing without disturbing the rest of the apparatus.

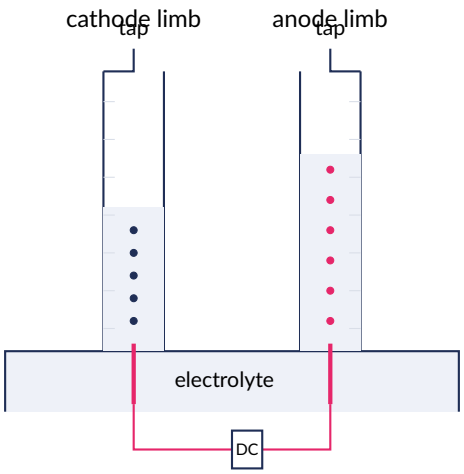


Figure 2. Hofmann voltameter: gas produced at each electrode collects at the top of its own graduated limb, pushing electrolyte down the scale so the two volumes can be compared; a tap lets a gas sample be withdrawn for testing.

Simple gas tests used to identify electrolysis products:

Gas	Test	Positive result
H_2	hold a lighted splint to the mouth of the tube	burns with a squeaky "pop"
O_2	insert a glowing splint	splint relights
Cl_2	hold damp blue litmus paper in the gas	litmus is bleached (turns white)
CO_2	bubble the gas through limewater	limewater turns milky/cloudy

Ví dụ mẫu · Testing the products of dilute sulfuric acid electrolysis

A Hofmann voltameter containing dilute sulfuric acid is connected to a battery. After several minutes, gas has collected in both limbs.

Observation 1: the volume of gas in the cathode limb is roughly twice that in the anode limb. This matches the mole ratio in $2H_2O -> 2H_2 + O_2$: for every 2 volumes of H_2 produced, only 1 volume of O_2 forms.

Observation 2: opening the tap on the cathode limb and applying a lighted splint gives a squeaky "pop" — confirming H_2.

Observation 3: opening the tap on the anode limb and inserting a glowing splint relights it — confirming O_2.

Together, these observations confirm that dilute sulfuric acid is effectively catalysing the decomposition of water; the acid itself is not used up, so its concentration slowly increases as electrolysis proceeds and water is removed.

4.2 Electrolysis of molten binary ionic compounds

In a *molten* binary ionic compound (one metal/cation, one non-metal/anion, no water present) there is only one type of cation and one type of anion, so the electrolysis products are straightforward to predict — there is no competition between different ions for discharge.

Ví dụ mẫu · Molten lead(II) bromide

Molten lead(II) bromide, $PbBr_2$, is electrolysed using carbon (inert) electrodes.
Step 1 — identify the ions: Pb^{2+} (cation) and Br^- (anion) — nothing else is present.
Step 2 — cathode (reduction): $Pb^{2+} + 2e^- -> Pb$ — grey molten lead metal collects at the cathode.
Step 3 — anode (oxidation): $2Br^- -> Br_2 + 2e^-$ — orange-brown bromine vapour is released at the anode.
Check: atoms balance (1 Pb, 2 Br each side) and charge balances ($2+$ and $2-$ cancelled by the $2e^-$ on each side).

Ví dụ mẫu · Molten zinc chloride

Molten zinc chloride, $ZnCl_2$, is electrolysed using inert electrodes. Only two types of ion are present: Zn^{2+} and Cl^-.
Step 1 — identify the ions: cation Zn^{2+}, anion Cl^- (no competition, since it is molten, not aqueous).
Step 2 — cathode: $Zn^{2+} + 2e^- -> Zn$ — grey zinc metal collects at the cathode.
Step 3 — anode: $2Cl^- -> Cl_2 + 2e^-$ — pale green-yellow chlorine gas is released at the anode, recognisable by its smell and by its ability to bleach damp litmus paper.

More molten binary electrolytes (inert/carbon electrodes):

Molten electrolyte	Cathode half-equation	Anode half-equation
$PbBr_2$	$Pb^{2+} + 2e^- -> Pb$	$2Br^- -> Br_2 + 2e^-$
$PbCl_2$	$Pb^{2+} + 2e^- -> Pb$	$2Cl^- -> Cl_2 + 2e^-$
$ZnCl_2$	$Zn^{2+} + 2e^- -> Zn$	$2Cl^- -> Cl_2 + 2e^-$
$MgCl_2$	$Mg^{2+} + 2e^- -> Mg$	$2Cl^- -> Cl_2 + 2e^-$
Al_2O_3 (conceptual, pure)	$Al^{3+} + 3e^- -> Al$	$2O^{2-} -> O_2 + 4e^-$

In every case, the metal cation is reduced at the cathode to the free metal, and the non-metal anion is oxidised at the anode to the free element. Note the last row: in practice, pure molten Al_2O_3 is never used industrially on its own — it is always dissolved in molten cryolite first (Section 4.4), but the half-equations for which ions discharge are unaffected by that choice.

VN **GIẢI THÍCH TIẾNG VIỆT**
Với hợp chất ion nóng chảy chỉ có **một loại cation** và **một loại anion**, nên sản phẩm điện phân rất dễ dự đoán: cation kim loại luôn bị khử thành kim loại tự do ở cathode, anion phi kim luôn bị oxi hoá thành đơn chất ở anode — không có sự cạnh tranh phóng điện như trong dung dịch nước. Chỉ cần viết đúng ion, cân bằng nguyên tử và cân bằng điện tích (số electron hai vế bằng nhau) là xong.

(!) Lỗi thường gặp: When writing a half-equation, the number of electrons must make the *charge* balance on both sides, not just the atoms. For $Pb^{2+} + 2e^- -> Pb$: left-hand charge is $(+2) + (-2) = 0$; right-hand charge is 0 — balanced. A very common error is to write $Pb^{2+} + e^- -> Pb$ (only one electron) — the atoms still balance (1 Pb each side) but the charge does not ($+2 - 1 = +1 \neq 0$). Always check *both* atoms and charge before accepting a half-

equation as correct, and remember that for a 2+ or 3+ cation you need 2 or 3 electrons respectively, matching the size of the charge exactly.

4.3 Electrolysis of aqueous solutions

When the electrolyte is an *aqueous solution*, water itself contributes small numbers of H^+ and OH^- ions (from its own slight self-ionisation), so more than one type of cation and more than one type of anion are present, and there is genuine *competition* for discharge at each electrode. Which ion actually gets discharged follows two consistent rules.

4.3.1 Discharge rules

Rule for cations (at the cathode): the *least reactive* cation present is discharged. Using the reactivity series,

$$K > Na > Ca > Mg > Al > (C) > Zn > Fe > (H) > Cu > Ag$$

if the metal is **above hydrogen** (K, Na, Ca, Mg, Al, Zn, Fe), H^+ is discharged instead and hydrogen gas is released; the metal ion is left behind in solution. If the metal is **below hydrogen** (Cu, Ag), the metal ion is discharged in preference to H^+, and the metal is deposited on the cathode.

Rule for anions (at the anode): ease of discharge increases in the order

$$SO_4^{2-},\ NO_3^- \ <\ OH^- \ <\ Cl^-,\ Br^- \ <\ I^-$$

SO_4^{2-} and NO_3^- are *never* discharged in aqueous solution — OH^- is always discharged instead, releasing O_2. A **concentrated** halide (Cl^- or Br^-) is discharged in preference to OH^-, releasing the halogen; in a **dilute** chloride or bromide solution, OH^- tends to win instead, releasing O_2. Iodide, I^-, is discharged in preference to OH^- even in fairly dilute solution, since it is the easiest halide ion of the three to oxidise.

Discharge-rules summary (aqueous electrolysis, inert electrodes):

Electrode	Which ion wins	Typical product
Cathode	Least reactive cation present: metal below H (e.g. Cu, Ag) deposits; if the metal is above H, H^+ is discharged instead	Metal deposit, *or* H_2 gas
Anode	SO_4^{2-}/NO_3^- never discharged (default is OH^-); a concentrated halide (Cl^-, Br^-) beats OH^-; I^- always beats OH^-	O_2 gas, *or* a halogen (Cl_2, Br_2, I_2)

VN **GIẢI THÍCH TIẾNG VIỆT**

Quy tắc phóng điện ưu tiên: ở **cathode**, ion kim loại **kém hoạt động hơn** bị phóng điện trước — nếu kim loại đứng **trên** hydro trong dãy hoạt động hoá học thì H^+ bị khử thay (thoát khí H_2); nếu kim loại đứng **dưới** hydro (như Cu, Ag) thì chính ion kim loại đó bị khử. Ở **anode**: SO_4^{2-}/NO_3^- **không bao giờ** bị phóng điện (luôn là OH^- thay thế, thoát khí O_2); halogenua **đặc** (Cl^-, Br^-) thắng OH^-; riêng iotua I^- luôn thắng OH^- kể cả khi loãng.

(!) Lỗi thường gặp: The single most common mistake in this topic is applying the "concentrated beats OH^-" rule without checking the actual concentration stated in the question. A **dilute** chloride or bromide solution (e.g. dilute sodium bromide) still gives O_2 at the anode, *not* the halogen, because OH^- wins when the halide concentration is low. Only a **concentrated** chloride or bromide solution (or any concentration of iodide) gives the halogen. Note also that this caveat does not apply to dilute acids such as hydrochloric acid: because the solution is acidic, the OH^- concentration is pushed to extremely low levels, so even "dilute" hydrochloric acid still releases Cl_2 at the anode (Example below) — always read whether the electrolyte is a *neutral halide salt solution* or an *acid* before applying the concentration caveat.

Inert vs. reactive electrodes:

Electrode type	Examples	Behaviour
Inert	graphite (carbon), platinum	does not react itself; the anode reaction is decided purely by which anion in solution is easiest to discharge
Reactive	copper, silver, other easily-oxidised metals	the electrode metal itself is oxidised at the anode in preference to any anion, e.g. $Cu -> Cu^{2+} + 2e^-$

(!) Lỗi thường gặp: The identity of the electrode material matters as much as the electrolyte. With *inert* electrodes, only the ions already in solution can be discharged, so the cation and anion preferential-discharge rules apply directly. With a *reactive* electrode (e.g. copper or silver), the electrode metal itself may be oxidised at the anode instead of any ion in solution — always check what the electrodes are made of before deciding on the anode reaction.

4.3.2 Worked examples of aqueous electrolysis

Ví dụ mẫu · Concentrated aqueous sodium chloride (brine)

Ions present: Na^+, H^+ (cations); Cl^-, OH^- (anions). Sodium is far more reactive than hydrogen, so H^+ is discharged at the cathode: $2H^+ + 2e^- -> H_2$. Cl^- is concentrated, so it is discharged in preference to OH^- at the anode: $2Cl^- -> Cl_2 + 2e^-$. Sodium and hydroxide ions are left behind in solution as sodium hydroxide. This is the industrial *chlor-alkali process*: it manufactures H_2, Cl_2, and NaOH solution simultaneously from brine.

Why sodium metal is never obtained from aqueous NaCl

Molten sodium chloride (no water at all) gives sodium metal at the cathode: $Na^+ + e^- -> Na$. But however concentrated an aqueous solution of sodium chloride is made, the cathode product is always H_2, never sodium metal — because water always supplies H^+, an easier cation to discharge than Na^+, since sodium is far more reactive than hydrogen. This is precisely why reactive metals such as sodium, magnesium and aluminium must always be extracted from a *molten*, water-free electrolyte: extraction from an aqueous solution of their salts is simply impossible, no matter the concentration.

Ví dụ mẫu · Dilute sulfuric acid

Dilute sulfuric acid is electrolysed using inert (platinum) electrodes. Ions present: H^+ (cation); SO_4^{2-}, OH^- (anions).
Cathode: $2H^+ + 2e^- -> H_2$ (only cation present is discharged).
Anode: $4OH^- -> O_2 + 2H_2O + 4e^-$ (SO_4^{2-} is never discharged, so OH^- is discharged instead).
Check: anode atoms — left 4 O and 4 H; right 2 O (in O_2) $+2$ O (in $2H_2O$) $= 4$ O, and 4 H (in $2H_2O$). Charge — left $4(-1) = -4$; right $0 + 0 + 4(-1) = -4$. Balanced.
Overall this is simply the decomposition of water, $2H_2O -> 2H_2 + O_2$: twice the volume of H_2 forms compared with O_2, and the acid becomes gradually more concentrated as water is used up.

Ví dụ mẫu · Dilute copper(II) sulfate — inert electrodes

Dilute aqueous copper(II) sulfate, $CuSO_4$, is electrolysed using graphite (inert) electrodes. Ions present: Cu^{2+}, H^+ (cations); SO_4^{2-}, OH^- (anions).
Cathode: copper is below hydrogen, so Cu^{2+} is discharged in preference to H^+: $Cu^{2+} + 2e^- -> Cu$ — a pink-brown deposit of copper forms.
Anode: SO_4^{2-} is never discharged, so OH^- is discharged instead: $4OH^- -> O_2 + 2H_2O + 4e^-$ — oxygen gas is released.
As electrolysis continues, the blue colour of the solution gradually fades: Cu^{2+} ions are steadily removed at the cathode but are *not* replaced, because the inert graphite anode does not dissolve.

Ví dụ mẫu · Dilute copper(II) sulfate — copper electrodes (contrast)

The same dilute $CuSO_4$ solution is now electrolysed using two *copper* electrodes instead of graphite.
Cathode: unchanged — $Cu^{2+} + 2e^- -> Cu$; copper still deposits.
Anode: the copper metal of the electrode itself is oxidised, in preference to either SO_4^{2-} or OH^-, since it is far easier to remove electrons from solid copper atoms than from those anions: $Cu -> Cu^{2+} + 2e^-$ — no gas is produced at all.
Contrast with the inert case above: here, copper simply transfers from the anode to the cathode; the Cu^{2+} concentration and the blue colour of the solution stay constant, the anode loses mass, and the cathode gains mass by exactly the same amount. This reactive-electrode behaviour is exactly the basis of the industrial purification of copper (Section 4.5).

Ví dụ mẫu · Dilute hydrochloric acid

Dilute hydrochloric acid is electrolysed using inert electrodes. Ions present: H^+ (the only cation); Cl^- and OH^- (anions).
Cathode: $2H^+ + 2e^- -> H_2$ — the only cation present is discharged.
Anode: $2Cl^- -> Cl_2 + 2e^-$ — chlorine gas (pale green-yellow, bleaches damp litmus) is released.
Even though the acid is described as "dilute," the solution is acidic, which keeps the OH^- concentration extremely low; the chloride ions therefore easily out-compete OH^- regardless of how dilute the acid is. This is different from a *neutral* salt solution such as dilute sodium chloride, where a low chloride concentration would allow OH^- to win instead.

VN **GIẢI THÍCH TIẾNG VIỆT**

Với dung dịch nước, luôn xác định **ion nào có mặt** trước, sau đó áp dụng hai quy tắc phóng điện ưu tiên. Ba cặp ví dụ quan trọng nhất cần phân biệt rõ: (1) NaCl nóng chảy cho kim loại Na, còn NaCl hoà tan luôn cho khí H_2 ở cathode; (2) $CuSO_4$ với điện cực trơ làm nhạt màu dung dịch dần, còn với điện cực đồng thì màu và nồng độ không đổi; (3) halogenua **loãng** (trừ iotua) cho khí O_2 ở anode, còn axit HCl (dù loãng) vẫn luôn cho khí Cl_2 vì môi trường axit làm nồng độ OH^- cực thấp.

4.4 Industrial extraction of aluminium

Aluminium lies above carbon in the reactivity series, so its ore cannot be reduced using carbon in the way iron oxide can (a more reactive metal's oxide cannot be reduced by a less reactive element) — electrolysis must be used instead. Purified aluminium oxide, Al_2O_3 (obtained from bauxite ore), melts at over 2000°C on its own, far too hot to be practical or economical. Dissolving it in molten **cryolite** (Na_3AlF_6) instead brings the operating temperature of the mixture down to roughly 950°C — still hot, but achievable, and far more energy-efficient than melting pure Al_2O_3 alone. Molten cryolite therefore serves purely as a solvent; it plays no chemical part in the electrode reactions themselves.

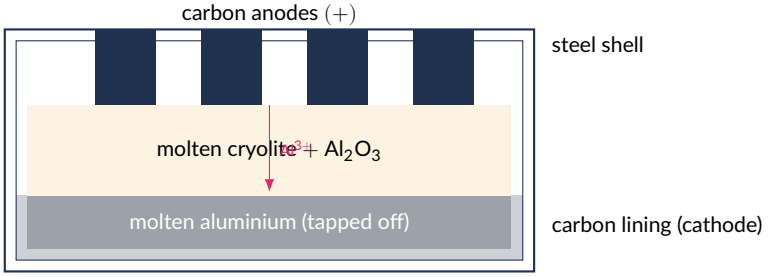


Figure 3. Simplified Hall–Héroult cell: purified Al_2O_3 dissolved in molten cryolite is electrolysed between carbon anodes dipping from above and a carbon lining acting as the cathode. Molten aluminium, denser than the electrolyte, sinks and collects at the bottom.

Ví dụ mẫu · Aluminium extraction — half-equations

The electrolyte is molten cryolite with dissolved Al_2O_3; the ions present are Al^{3+} and O^{2-} (the cryolite's own ions, Na^+ and AlF_6^{3-}, are not discharged — cryolite only serves to lower the melting point).

Cathode (carbon lining): $Al^{3+} + 3e^- -> Al$ — molten aluminium collects at the bottom of the cell, since it is denser than the electrolyte, and is tapped off periodically.

Anode (carbon blocks): $2O^{2-} -> O_2 + 4e^-$ — the hot oxygen produced reacts with the carbon anode itself, $C + O_2 -> CO_2$, so the anodes gradually burn away and must be replaced regularly; this is a genuine running cost of the process.

Overall (for the electrode pair, lowest common multiple of electrons $= 12$): combining $4 \times (Al^{3+} + 3e^- -> Al)$ with $3 \times (2O^{2-} -> O_2 + 4e^-)$ gives $4Al^{3+} + 6O^{2-} -> 4Al + 3O_2$, i.e. $2Al_2O_3 -> 4Al + 3O_2$ overall.

VN **GIẢI THÍCH TIẾNG VIỆT**

Nhôm hoạt động mạnh hơn carbon nên không thể dùng carbon để khử Al_2O_3 như cách khử quặng sắt — phải dùng điện phân. Criolit nóng chảy chỉ đóng vai trò **làm giảm nhiệt độ nóng chảy** của Al_2O_3 (từ hơn 2000°C xuống khoảng 950°C), tiết kiệm năng lượng đáng kể, chứ bản thân ion của criolit **không** bị điện phân. Anode carbon phải thay thường xuyên vì khí oxi sinh ra phản ứng với chính carbon tạo CO_2.

4.5 Purification of copper

Copper extracted from ore by smelting is not pure enough for high-quality electrical wiring (even small amounts of impurity greatly reduce its conductivity), so it is purified further by **electrorefining**. Impure copper is made the **anode**; a thin sheet of pure copper is the **cathode**; the electrolyte is aqueous copper(II) sulfate.

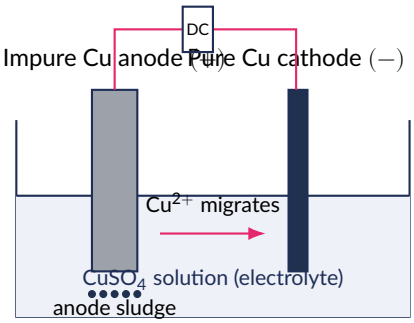


Figure 4. Electrorefining of copper: the impure anode dissolves ($Cu -> Cu^{2+} + 2e^-$) while pure copper deposits at the cathode ($Cu^{2+} + 2e^- -> Cu$); unreactive impurities such as silver and gold fall to the bottom as anode sludge.

Ví dụ mẫu · Copper purification — half-equations

Electrolyte: aqueous $CuSO_4$. Anode: impure copper. Cathode: thin sheet of pure copper.

Anode (oxidation): $Cu -> Cu^{2+} + 2e^-$ — the impure copper dissolves, releasing Cu^{2+} into solution. Any less reactive metal impurities present (e.g. silver, gold) are *not* oxidised, since they are harder to oxidise than copper, and simply fall away as solid particles — the "anode sludge."

Cathode (reduction): $Cu^{2+} + 2e^- -> Cu$ — only pure copper is deposited onto the growing cathode.

Net effect: copper atoms are transferred, atom for atom, from the impure anode to the pure cathode; the $CuSO_4$ electrolyte concentration stays essentially constant throughout, since every Cu^{2+} ion removed at the cathode is replaced by one released at the anode. The valuable anode sludge (often containing silver and gold) is collected and processed separately.

VN **GIẢI THÍCH TIẾNG VIỆT**

Trong tinh luyện đồng: đồng **không tinh khiết** làm anode, bị oxi hoá tan ra ($Cu -> Cu^{2+} + 2e^-$); đồng **tinh khiết** làm cathode, nhận lại ion đó ($Cu^{2+} + 2e^- -> Cu$). Tạp chất kém hoạt động hơn đồng (như Ag, Au) không bị oxi hoá, rơi xuống đáy thành "bùn anode" — đây chính là nguồn thu hồi kim loại quý giá trong công nghiệp.

4.6 Electroplating

Electroplating coats an object with a thin, even layer of a different metal, usually to improve its appearance or to protect it from corrosion. The general principle is always the same: the object to be plated is made the **cathode**; a bar or rod of the plating metal is made the **anode**; the electrolyte is a solution containing ions of the plating metal.

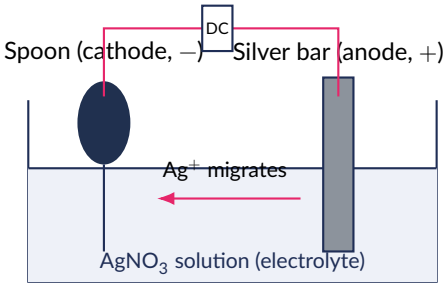


Figure 5. Silver-plating a spoon: the spoon is made the cathode ($Ag^+ + e^- -> Ag$ deposits a thin silver layer); the silver bar anode dissolves ($Ag -> Ag^+ + e^-$) to keep the Ag^+ concentration in solution constant.

Ví dụ mẫu · Electroplating an iron spoon with silver

An iron spoon is to be silver-plated.

Setup: the spoon is connected to the negative terminal of the d.c. supply (making it the **cathode**); a bar of pure silver is connected to the positive terminal (the **anode**); both dip into a solution containing silver ions, e.g. aqueous silver nitrate, $AgNO_3$.

Cathode (spoon): $Ag^+ + e^- -> Ag$ — silver ions from solution are reduced and deposited as a thin, even, shiny layer of solid silver onto the spoon's surface.

Anode (silver bar): $Ag -> Ag^+ + e^-$ — the silver bar dissolves, continuously replacing the Ag^+ ions removed from solution at the cathode, so the concentration of the electrolyte (and the rate of plating) stays steady throughout.

Result: the spoon ends up with a thin, tightly-bonded coating of silver metal, giving it the appearance of solid silver at a much lower cost, while the silver anode gradually loses mass.

Common electroplating examples:

Object plated	Plating metal	Main purpose
Steel cutlery	Silver	appearance (looks like solid silver) at lower cost
Steel car parts / bumpers, taps	Chromium	bright, attractive finish; resists corrosion and scratching
Steel food cans	Tin	tin is unreactive with food acids and non-toxic, forming a protective barrier

(!) Lỗi thường gặp: Do not assume every metal coating protects the underlying metal in the same way. **Galvanising** (coating steel with *zinc*) gives sacrificial protection: zinc is *more* reactive than iron, so even if the coating is scratched, the zinc corrodes preferentially and protects the exposed iron. **Tin-plating** steel cans is different: tin is *less* reactive than iron, so it only protects by acting as a physical barrier — if the tin coating is scratched, the exposed iron will actually corrode *faster* than uncoated steel would, because the less reactive tin does not sacrifice itself. Always check whether the coating metal is more or less reactive than the metal underneath before describing how it protects.

VN **GIẢI THÍCH TIẾNG VIỆT**

Nguyên tắc mạ điện luôn không đổi: vật cần mạ luôn là **cathode**, thanh kim loại mạ luôn là **anode**, dung dịch điện li phải chứa ion của kim loại mạ. Mạ bạc lên dao nĩa (đẹp, rẻ hơn bạc nguyên chất), mạ crom lên phụ tùng ô tô (đẹp, chống ăn mòn), mạ thiếc lên vỏ lon thực phẩm (thiếc trơ với axit thực phẩm) là ba ứng dụng tiêu biểu. Lưu ý: mạ kẽm (galvanising) bảo vệ

ngay cả khi trầy xước (vì kẽm hoạt động mạnh hơn sắt, ăn mòn thay), còn mạ thiếc chỉ bảo vệ khi lớp mạ còn nguyên vẹn.

4.7 Simple chemical cells

(Supplement) Placing two *different* metals in an electrolyte and connecting them with a wire (and a voltmeter) generates a voltage — this is a simple chemical (voltaic) cell. The more reactive metal loses electrons more readily, so it becomes the **negative terminal**; electrons flow through the external wire from the more reactive metal to the less reactive one. The size of the reactivity *gap* between the two metals determines roughly how large the voltage is: a bigger gap produces a bigger voltage. Everyday batteries are simply chemical cells (or several joined together) sealed inside a case, with the reactive-metal chemistry chosen to give a convenient, steady voltage.

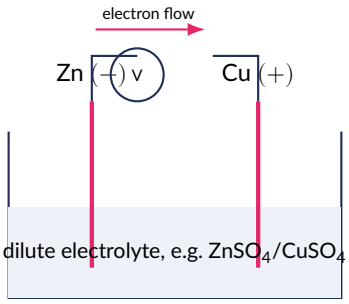


Figure 6. A simple zinc–copper cell: zinc, being more reactive, loses electrons more readily and is the negative terminal; electrons flow through the external wire and voltmeter from zinc to copper.

Electrolytic cells vs. simple (voltaic) cells:

	Electrolytic cell	Simple (voltaic) cell
Energy conversion	electrical → chemical	chemical → electrical
Power source	external d.c. supply required	none — generates its own current
Reaction	non-spontaneous, driven by the supply	spontaneous, driven by the reactivity gap
Electrode terms	cathode $(-)$, anode $(+)$	negative terminal, positive terminal

(!) Lỗi thường gặp: Do not confuse electrode polarity between the two types of cell. In an **electrolytic** cell (with an external d.c. supply), the cathode is the *negative* electrode and reduction happens there. In a **simple/voltaic** cell (which generates its own current spontaneously), we refer instead to the more reactive metal as the *negative terminal* — avoid calling it the "cathode," since that term is reserved for electrolysis at this level, and mixing the two vocabularies is a very common source of lost marks.

Relative voltage produced by different metal pairs (larger reactivity gap ⇒ larger voltage; more reactive metal = negative terminal):

Metal pair	Negative terminal	Reactivity gap	Relative voltage
Mg & Cu	Mg	very large	largest
Zn & Cu	Zn	large	large
Fe & Cu	Fe	moderate	moderate
Zn & Fe	Zn	small	smallest

Ví dụ mẫu · Ranking simple-cell voltage · (Supplement)

(Supplement) Three simple cells are set up, each pairing a different metal with copper in dilute sulfuric acid: magnesium–copper, zinc–copper, and iron–copper. Rank the voltmeter readings from largest to smallest, and identify the negative terminal in each.

Step 1 — locate each metal in the reactivity series relative to copper: Mg is very far above Cu; Zn is well above Cu; Fe is only moderately above Cu.

Step 2 — apply the rule (bigger reactivity gap = bigger voltage): Mg–Cu has the largest gap, then Zn–Cu, then Fe–Cu.

Ranking: Mg–Cu > Zn–Cu > Fe–Cu.

Negative terminal in each cell: the more reactive metal — Mg in the first cell, Zn in the second, Fe in the third; copper is the positive terminal in all three, since it is the least reactive metal in every pair.

VN **GIẢI THÍCH TIẾNG VIỆT**

(Supplement) Ghép hai kim loại khác nhau vào cùng một dung dịch điện li rồi nối dây dẫn sẽ sinh ra hiệu điện thế. Kim loại **hoạt động mạnh hơn** nhường electron dễ hơn nên là cực **âm**; electron chạy qua dây dẫn ngoài từ kim loại mạnh sang kim loại yếu hơn. **Khoảng cách hoạt động hoá học** giữa hai kim loại càng lớn thì hiệu điện thế sinh ra càng lớn — ví dụ cặp Mg–Cu cho hiệu điện thế lớn hơn cặp Fe–Cu.

Chapter summary — electrochemistry at a glance:

Term/rule	Meaning
Cathode	negative electrode; cations are reduced (gain electrons) here
Anode	positive electrode; anions (or a reactive electrode) are oxidised (lose electrons) here
Cation rule	least reactive metal ion present is discharged; if the metal is above H, H^+ is discharged instead
Anion rule	SO_4^{2-}/NO_3^- never discharged; concentrated halide beats OH^-; I^- always beats OH^-
Aluminium extraction	electrolysis of Al_2O_3 dissolved in molten cryolite (carbon anode burns away)
Copper purification	impure Cu anode dissolves, pure Cu deposits at cathode, $CuSO_4$ electrolyte
Electroplating	object = cathode; plating metal = anode; electrolyte supplies plating-metal ions
Simple cell (Supplement)	bigger reactivity gap between the two metals = bigger voltage; more reactive metal = negative terminal

Practice

Bài tập luyện tập

At which electrode of an electrolytic cell does reduction always take place?

(A) The anode, because it is positive

(B) The cathode, because cations gain electrons there

(C) Either electrode, depending on the electrolyte

(D) Neither — electrolysis does not involve reduction

Lời giải chi tiết

Cations migrate to the cathode and gain electrons (reduction) there; this is true for every electrolytic cell. **(B)**.

Bài tập luyện tập

Molten lead(II) bromide is electrolysed using carbon electrodes. What forms at the cathode and anode respectively?

(A) Br_2; Pb

(B) Pb; Br_2

(C) H_2; O_2

(D) Pb; O_2

Lời giải chi tiết

Only Pb^{2+} and Br^- ions are present. Cathode (reduction): $Pb^{2+} + 2e^- -> Pb$. Anode (oxidation): $2Br^- -> Br_2 + 2e^-$. **(B)**.

Bài tập luyện tập

Write balanced half-equations for the cathode and anode reactions when molten magnesium chloride, $MgCl_2$, is electrolysed.

Lời giải chi tiết

Cathode: $Mg^{2+} + 2e^- -> Mg$ (silvery magnesium metal). Anode: $2Cl^- -> Cl_2 + 2e^-$ (pale green chlorine gas).

Bài tập luyện tập

Write balanced half-equations for the cathode and anode reactions when molten lead(II) chloride, $PbCl_2$, is electrolysed, and state what is observed at each electrode.

Lời giải chi tiết

Cathode: $Pb^{2+} + 2e^- -> Pb$ (grey molten lead collects). Anode: $2Cl^- -> Cl_2 + 2e^-$ (pale green-yellow chlorine gas, bleaches damp litmus).

Bài tập luyện tập

Explain why molten aluminium oxide alone (without cryolite) is not used industrially, even though the half-equations for its electrolysis are straightforward.

Lời giải chi tiết

The preferential-discharge half-equations ($Al^{3+} + 3e^- -> Al$ at the cathode; $2O^{2-} -> O_2 + 4e^-$ at the anode) are indeed simple, but pure Al_2O_3 has an extremely high melting point (over 2000°C), so melting it alone would need enormous amounts of energy. Dissolving it in molten cryolite lowers the operating temperature substantially (to roughly 950°C), making the process economically viable, without changing which ions are discharged.

Bài tập luyện tập

Dilute sulfuric acid is electrolysed with inert electrodes. What gases form at the cathode and anode, and in what volume ratio (cathode:anode)?

(A) O_2 and H_2, 1:2

(B) H_2 and O_2, 2:1

(C) H_2 and O_2, 1:1

(D) SO_2 and O_2, 1:1

Lời giải chi tiết

H^+ is discharged at the cathode (H_2); OH^- is discharged at the anode (O_2), since SO_4^{2-} is never discharged. From $2H_2O -> 2H_2 + O_2$, the volume ratio $H_2 : O_2 = 2 : 1$. **(B)**.

Bài tập luyện tập

During the electrolysis of dilute sulfuric acid, $40\,cm^3$ of gas is collected at the anode. What volume of gas would be collected at the cathode in the same time?

(A) $20\,\text{cm}^3$
(B) $40\,\text{cm}^3$
(C) $80\,\text{cm}^3$
(D) $160\,\text{cm}^3$

Lời giải chi tiết

The volume ratio cathode:anode (H_2 : O_2) is $2:1$, so the cathode volume is twice the anode volume: $2 \times 40 = 80\,\text{cm}^3$. **(C)**.

Bài tập luyện tập

Explain why aluminium is extracted by electrolysis rather than by reduction with carbon, even though electrolysis uses far more energy.

Lời giải chi tiết

Aluminium is more reactive than carbon (it lies above carbon in the reactivity series), so carbon cannot remove oxygen from Al_2O_3 — carbon can only reduce the oxides of metals *less* reactive than itself. Electrolysis must be used instead, since it can extract very reactive metals regardless of their position relative to carbon.

Bài tập luyện tập

Write the half-equation for the reaction occurring at the anode when concentrated hydrochloric acid is electrolysed.

Lời giải chi tiết

Cl^- ions are oxidised (lose electrons) at the anode: $2Cl^- -> Cl_2 + 2e^-$. (As shown in the worked example above, this is also true for *dilute* hydrochloric acid, since the acidic solution keeps the competing OH^- concentration very low.)

Bài tập luyện tập

A solution contains both Na^+ and Cu^{2+} ions. When electrolysed with inert electrodes, which ion is discharged at the cathode, and why?

(A) Na^+, because sodium is more reactive
(B) Cu^{2+}, because copper is less reactive than hydrogen
(C) Both ions equally
(D) Neither — only water is decomposed

Lời giải chi tiết

Copper lies below hydrogen in the reactivity series, so Cu^{2+} is discharged in preference to both Na^+ (far more reactive, stays in solution) and H^+. **(B)**.

Bài tập luyện tập

Dilute aqueous sodium hydroxide is electrolysed using inert electrodes. Identify the products at each electrode and write both half-equations.

Lời giải chi tiết

Only Na^+, H^+ (cations) and OH^- (anion, in large excess since NaOH is a strong alkali) are present, plus trace ions from water. Cathode: $2H^+ + 2e^- -> H_2$. Anode: $4OH^- -> O_2 + 2H_2O + 4e^-$. Overall this is simply the electrolysis of water, since neither Na^+ nor OH^- is used up — the NaOH becomes more concentrated as electrolysis proceeds.

Bài tập luyện tập

A dilute solution of potassium iodide, KI, is electrolysed with inert electrodes. What would you expect to observe at the anode, and why is this different from what happens with a dilute chloride solution?

Lời giải chi tiết

Brown/purple iodine, I_2, would form at the anode: $2I^- -> I_2 + 2e^-$. Unlike chloride (which loses to OH^- when dilute), iodide is discharged in preference to OH^- even in dilute solution, since I^- is the easiest halide ion to oxidise.

Bài tập luyện tập

Concentrated aqueous copper(II) chloride is electrolysed using inert electrodes. Write both half-equations and state what is observed at each electrode.

Lời giải chi tiết

Cathode: $Cu^{2+} + 2e^- -> Cu$ (copper is less reactive than hydrogen, so it is discharged; a pink-brown deposit of copper forms). Anode: $2Cl^- -> Cl_2 + 2e^-$ (the halide is concentrated, so it beats OH^-; a choking pale green-yellow gas is released, which bleaches damp litmus paper).

Bài tập luyện tập

In electroplating an iron spoon with silver, which electrode is the spoon connected to, and what is the electrolyte?

(A) Anode; molten AgCl

(B) Cathode; a solution containing Ag^+ ions

(C) Anode; a solution containing Fe^{2+} ions

(D) Cathode; molten iron

Lời giải chi tiết

The object to be plated is always the **cathode** (so plating-metal cations from solution are reduced and deposited onto it); the electrolyte must supply the plating metal's ions, e.g. silver nitrate solution. **(B)**.

Bài tập luyện tập

Dilute copper(II) sulfate is electrolysed first with two graphite electrodes, then (in a fresh sample) with two copper electrodes. Describe and explain one key difference between the two experiments.

Lời giải chi tiết

With graphite (inert) electrodes, the anode reaction is $4OH^- -> O_2 + 2H_2O + 4e^-$ (oxygen gas released) and the blue colour of the solution fades over time, since Cu^{2+} is removed at the cathode but not replaced. With copper electrodes, the anode itself dissolves, $Cu -> Cu^{2+} + 2e^-$, replacing the Cu^{2+} removed at the cathode — so the blue colour and concentration of the solution stay essentially constant, and the anode loses mass while the cathode gains mass.

Bài tập luyện tập

Aqueous silver nitrate, $AgNO_3$, is electrolysed using inert electrodes. Write both half-equations and explain your reasoning.

Lời giải chi tiết

Ions present: Ag^+, H^+ (cations); NO_3^-, OH^- (anions). Silver lies below hydrogen, so at the cathode Ag^+ is discharged: $Ag^+ + e^- -> Ag$ (a shiny silver deposit forms — the basis of silver electroplating). NO_3^- is never discharged (like SO_4^{2-}), so at the anode OH^- is discharged instead: $4OH^- -> O_2 + 2H_2O + 4e^-$.

Bài tập luyện tập

During the purification (electrorefining) of copper, small amounts of silver are found at the bottom of the electrolytic cell. Explain where this silver comes from and why it does not dissolve.

Lời giải chi tiết

The silver was present as an impurity in the impure copper anode. Silver is less reactive than copper, so it is much harder to oxidise than copper — as the anode dissolves ($Cu -> Cu^{2+} + 2e^-$), the silver is not oxidised and simply falls away as solid metal, forming "anode sludge" at the bottom of the cell.

Bài tập luyện tập

Which observation would confirm that a colourless gas collected at an electrode is hydrogen rather than oxygen?

(A) It turns damp litmus paper red

(B) It relights a glowing splint

(C) It burns with a squeaky pop when a lighted splint is applied

(D) It turns limewater milky

Lời giải chi tiết

Hydrogen is confirmed by the "squeaky pop" test with a lighted splint; a glowing splint relighting is the test for oxygen instead. **(C)**.

Bài tập luyện tập

(Supplement) A student sets up a simple cell using magnesium and copper electrodes in dilute sulfuric acid, and another using iron and copper electrodes. Which cell produces the larger

voltmeter reading, and why?

Lời giải chi tiết

The magnesium–copper cell produces the larger reading. The size of the voltage depends on the *gap* in reactivity between the two metals: magnesium is much more reactive than copper (a very large gap), whereas iron is only moderately more reactive than copper (a smaller gap) — a bigger reactivity gap gives a bigger voltage.

Bài tập luyện tập

(Supplement) In a simple zinc–iron cell, which metal is the negative terminal, and in which direction do electrons flow through the external wire?

(A) Iron is negative; electrons flow from iron to zinc

(B) Zinc is negative; electrons flow from zinc to iron

(C) Both are equally negative; no current flows

(D) Iron is negative; no electrons flow through the wire

Lời giải chi tiết

Zinc is more reactive than iron, so it loses electrons more readily and becomes the negative terminal; electrons flow through the external wire from the more reactive metal (zinc) to the less reactive one (iron). **(B)**.

Bài tập luyện tập

Explain, in terms of electron transfer, why the anode reaction is always classed as oxidation, whatever the electrolyte.

Lời giải chi tiết

At the anode, anions (or, with a reactive electrode, the electrode metal itself) *lose* electrons to the external circuit. Loss of electrons is the definition of oxidation (OIL RIG: Oxidation Is Loss), so the anode reaction is always an oxidation, regardless of which particular species is involved.

Bài tập luyện tập

A student electrolyses concentrated aqueous sodium chloride with inert electrodes, then switches to a fresh sample of dilute copper(II) sulfate with copper electrodes. Compare and explain the anode products in the two experiments.

Lời giải chi tiết

With concentrated NaCl, the anode releases chlorine gas: $2Cl^- -> Cl_2 + 2e^-$, since concentrated Cl^- beats OH^-. With dilute $CuSO_4$ and *copper* electrodes, no gas forms at the anode at all — the copper electrode itself dissolves, $Cu -> Cu^{2+} + 2e^-$, since it is far easier to oxidise the solid metal than either SO_4^{2-} or OH^-. The key difference is that the first anode is inert (ions in solution must be discharged) while the second is reactive (the electrode reacts instead).

Bài tập luyện tập

Which pair of ions, if both were present in the same aqueous solution, would result in oxygen gas (rather than a halogen) being released at an inert anode?

(A) Concentrated Cl^- and OH^-
(B) Dilute Br^- and OH^-
(C) Concentrated I^- and OH^-
(D) Concentrated Br^- and OH^-

Lời giải chi tiết

A *dilute* halide (other than iodide) loses to OH^- at the anode, so oxygen (from OH^- discharge) is released rather than bromine. **(B)**.

Bài tập luyện tập

State two reasons why the anode blocks in the Hall–Héroult cell for extracting aluminium need to be replaced regularly.

Lời giải chi tiết

The anode is made of carbon, and the oxygen gas produced there ($2O^{2-} -> O_2 + 4e^-$) reacts with the hot carbon: $C + O_2 -> CO_2$. This steadily burns away the anode material, so fresh carbon blocks must be lowered into the cell periodically to replace those consumed; without regular replacement, the anodes would eventually be consumed completely and the circuit would break.

Bài tập luyện tập

Explain why an object being electroplated must always be made the cathode, never the anode.

Lời giải chi tiết

Metal cations from the electrolyte are attracted to, and deposited (reduced) at, the cathode: $M^{n+} + ne^- -> M$. If the object were made the anode instead, it would itself be oxidised and dissolve away, rather than gaining a protective or decorative coating.

Bài tập luyện tập

(Supplement) Which of the following correctly ranks three metals from strongest to weakest negative terminal when each is separately paired with copper in a simple cell: magnesium, zinc, iron?

(A) Fe > Zn > Mg
(B) Mg > Zn > Fe
(C) Zn > Mg > Fe
(D) Mg > Fe > Zn

Lời giải chi tiết

The reactivity series order (most to least reactive) is Mg > Zn > Fe > Cu, so the reactivity gap with copper — and hence the strength of the negative terminal / size of the voltage — follows the same order: Mg > Zn > Fe. **(B)**.

Bài tập luyện tập

A student wrongly writes the anode half-equation for electrolysing dilute sulfuric acid as $SO_4^{2-} -> SO_2 + O_2 + 2e^-$. Explain what is wrong with this equation and give the correct half-equation.

Lời giải chi tiết

SO_4^{2-} ions are never discharged during aqueous electrolysis — they remain spectator ions in solution. The gas produced at the anode always comes from OH^- discharge instead: $4OH^- -> O_2 + 2H_2O + 4e^-$.

Bài tập luyện tập

Dilute and concentrated aqueous sodium bromide are each electrolysed with inert electrodes. State the gas released at the anode in each case.

(A) O_2 (dilute); Br_2 (concentrated)

(B) Br_2 in both cases

(C) O_2 in both cases

(D) Br_2 (dilute); O_2 (concentrated)

Lời giải chi tiết

In dilute NaBr, Br^- cannot compete with OH^-, so oxygen is released. In concentrated NaBr, the high concentration of Br^- allows it to beat OH^-, releasing bromine instead. **(A)**.

Bài tập luyện tập

A fixed mass of impure copper is refined by electrolysis using a $CuSO_4$ electrolyte. As the process continues, what happens to the mass of the anode and the mass of the cathode?

(A) Anode mass increases; cathode mass decreases

(B) Anode mass decreases; cathode mass increases

(C) Both masses increase

(D) Both masses stay constant

Lời giải chi tiết

The impure anode dissolves ($Cu -> Cu^{2+} + 2e^-$), so its mass *decreases*; pure copper is deposited at the cathode ($Cu^{2+} + 2e^- -> Cu$), so its mass *increases*. **(B)**.

Bài tập luyện tập

Explain why a solid ionic compound such as solid sodium chloride does not conduct electricity, even though it is made entirely of charged particles.

Lời giải chi tiết

In a solid ionic lattice, the ions are held tightly in fixed positions by strong electrostatic forces and can only vibrate — they cannot move from place to place to carry charge through the structure. Only when the lattice breaks down (molten) or the ions are separated and surrounded by water molecules (aqueous) are the ions free to move, allowing the compound to conduct and be electrolysed.

Bài tập luyện tập

(Supplement) Which statement correctly distinguishes an electrolytic cell from a simple (voltaic) cell?

(A) An electrolytic cell converts chemical energy to electrical energy; a voltaic cell needs a power supply

(B) A voltaic cell converts chemical energy to electrical energy spontaneously; an electrolytic cell needs an external supply to drive a non-spontaneous reaction

(C) Both require an external power supply

(D) Both generate their own electrical energy

Lời giải chi tiết

A voltaic (simple) cell produces its own current from a spontaneous reaction driven by the reactivity gap between two metals; an electrolytic cell requires an external d.c. supply to force a non-spontaneous decomposition to occur. **(B)**.

Bài tập luyện tập

(Supplement) Two students each build a simple cell: one uses magnesium and iron, the other uses iron and copper. Predict which cell gives the larger voltmeter reading, and identify the negative terminal in each cell.

Lời giải chi tiết

Magnesium and iron have a larger reactivity gap between them than iron and copper (Mg is far above Fe in the reactivity series, whereas Fe is only moderately above Cu), so the magnesium–iron cell gives the **larger** reading. In the Mg–Fe cell, magnesium (more reactive) is the negative terminal; in the Fe–Cu cell, iron (more reactive) is the negative terminal.

Bài tập luyện tập

A can of food is coated with tin, and a steel bucket is coated with zinc (galvanised). If both coatings are scratched deeply enough to expose the steel underneath, explain why the bucket resists further rusting at the scratch but the can does not.

Lời giải chi tiết

Zinc is *more* reactive than iron, so at the scratch on the galvanised bucket, zinc corrodes preferentially and continues to protect the exposed iron (sacrificial protection). Tin is *less* reactive than iron, so at the scratch on the can, the tin does not sacrifice itself; instead the exposed iron corrodes, and may even corrode faster than uncoated steel would. Tin-plating therefore only protects while the coating remains intact, unlike galvanising.

Bài tập luyện tập

Give the overall (combined) equation for the extraction of aluminium at the Hall–Héroult cell, starting from the two half-equations $Al^{3+} + 3e^- -> Al$ and $2O^{2-} -> O_2 + 4e^-$.

Lời giải chi tiết

The electrons must cancel: multiply the cathode half-equation by 4 and the anode half-equation by 3, so that both involve 12 electrons: $4Al^{3+} + 12e^- \rightarrow 4Al$ and $6O^{2-} \rightarrow 3O_2 + 12e^-$. Adding and cancelling the electrons gives $4Al^{3+} + 6O^{2-} -> 4Al + 3O_2$, which is the same as $2Al_2O_3 -> 4Al + 3O_2$.

Chemical Energetics

Mục tiêu Unit: Phân biệt phản ứng toả nhiệt/thu nhiệt và giải thích bằng giản đồ năng lượng (kể cả ảnh hưởng của chất xúc tác); đo sự thay đổi năng lượng bằng thực nghiệm và tính toán với công thức $q = mc\Delta T$, chuyển đổi sang đơn vị kJ/mol; tính ΔH bằng năng lượng liên kết (bond energy); so sánh nhiên liệu qua dữ liệu nhiệt lượng kế; hiểu pin nhiên liệu hydro–oxy và so sánh nguồn năng lượng tái tạo/không tái tạo.

5.1 Exothermic and endothermic reactions

5.1.1 Energy changes and the sign of ΔH

Every chemical reaction involves an overall transfer of energy between the reacting chemicals and their surroundings. Chemists record this transfer as the **enthalpy change**, ΔH, measured in kilojoules per mole (kJ/mol).

Exothermic reactions

An **exothermic** reaction *releases* energy (usually as heat) to the surroundings. Because energy leaves the chemical system, the products end up with *less* energy than the reactants, and by convention

$$\Delta H < 0 \quad (\Delta H \text{ is negative}).$$

The temperature of the surroundings (the reaction mixture, the test tube, the air around it) **rises**.

Endothermic reactions

An **endothermic** reaction *absorbs* energy from the surroundings. The products end up with *more* energy than the reactants, so

$$\Delta H > 0 \quad (\Delta H \text{ is positive}).$$

The temperature of the surroundings **falls**, because heat is being taken from it to drive the reaction.

VN **GIẢI THÍCH TIẾNG VIỆT**

Phản ứng **toả nhiệt (exothermic)**: hệ hoá học giải phóng năng lượng ra môi trường xung quanh $\Rightarrow$ sản phẩm có năng lượng *thấp hơn* chất phản ứng $\Rightarrow \Delta H < 0$ (âm) $\Rightarrow$ nhiệt độ môi trường **tăng**. Phản ứng **thu nhiệt (endothermic)**: hệ hấp thụ năng lượng từ môi trường $\Rightarrow$ sản phẩm có năng lượng *cao hơn* $\Rightarrow \Delta H > 0$ (dương) $\Rightarrow$ nhiệt độ môi trường **giảm**. Quy tắc dấu: hãy luôn hỏi "năng lượng đi vào hay đi ra khỏi hoá chất?" – nếu đi ra (toả nhiệt) thì ΔH âm.

5.1.2 Everyday examples

Exothermic ($\Delta H < 0$)	**Endothermic ($\Delta H > 0$)**
Combustion (burning fuels: wood, natural gas, petrol)	Thermal decomposition, e.g. $CaCO_3 -> CaO + CO_2$
Neutralisation of an acid by an alkali	Photosynthesis, $6CO_2 + 6H_2O -> C_6H_{12}O_6 + 6O_2$
Respiration (release of energy from glucose in cells)	Dissolving certain salts, e.g. ammonium nitrate in water
Adding water to concentrated sulfuric acid	Electrolysis (energy supplied as electricity)
Many oxidation (rusting) reactions	Melting and boiling (physical, not chemical, but still absorb energy)

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Ví dụ toả nhiệt quen thuộc: đốt cháy nhiên liệu, phản ứng trung hoà axit–bazơ, hô hấp tế bào (glucose + oxy → năng lượng). Ví dụ thu nhiệt: nhiệt phân đá vôi ($CaCO_3$), quang hợp (cây hấp thụ năng lượng ánh sáng để tạo glucose), hoà tan một số muối (như amoni nitrat) làm cốc nước lạnh đi rõ rệt – đây là dấu hiệu thực nghiệm dễ nhận biết nhất của phản ứng thu nhiệt.

5.1.3 Energy profile diagrams and activation energy

A **reaction/energy profile diagram** plots the energy of the chemicals against the progress of the reaction. Even an exothermic reaction needs a small input of energy to get started: colliding particles must have enough energy to break bonds before new ones can form. This minimum energy is the **activation energy**, E_a.

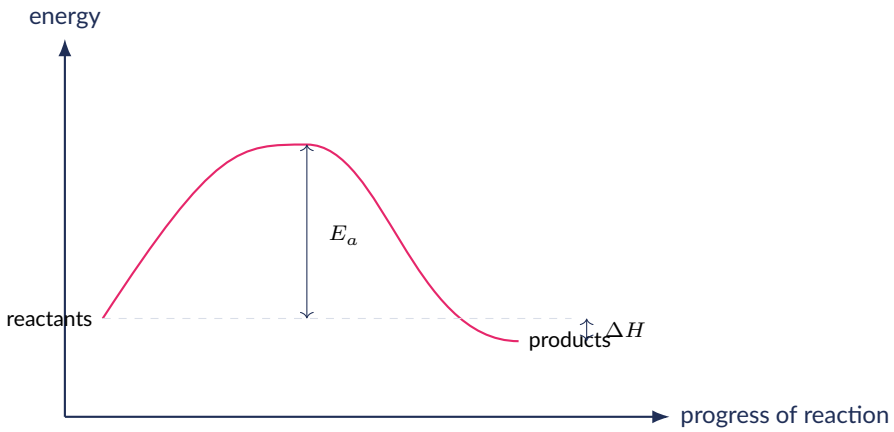

Figure 5.1. Energy profile for an exothermic reaction: products have lower energy than reactants ($\Delta H < 0$); the "hump" above the reactants is the activation energy E_a needed to start the reaction.

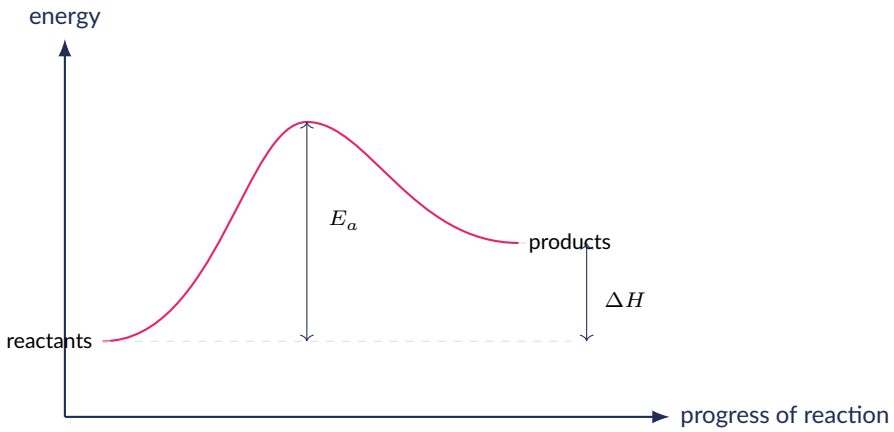

Figure 5.2. Energy profile for an endothermic reaction: products have higher energy than reactants ($\Delta H > 0$), so overall the reaction absorbs energy from the surroundings even though it, too, has an activation-energy barrier E_a to overcome first.

Key point: E_a is always positive (it is just a barrier height) and it is *not* the same thing as ΔH. A reaction can be strongly exothermic (ΔH very negative) yet still have a large E_a, which is why many exothermic reactions (e.g. burning natural gas) need a spark or flame to start, even though once started they release far more energy than they needed to begin.

VN **GIẢI THÍCH TIẾNG VIỆT**

Giản đồ năng lượng biểu diễn năng lượng của hệ theo tiến trình phản ứng. Với phản ứng toả nhiệt, sản phẩm nằm **thấp hơn** chất phản ứng trên trục năng lượng; với phản ứng thu nhiệt, sản phẩm nằm **cao hơn**. Dù toả hay thu nhiệt, đường cong luôn có một "đỉnh đồi" phía trên mức chất phản ứng – đó chính là năng lượng hoạt hoá E_a, năng lượng tối thiểu các hạt va chạm cần có để phản ứng xảy ra. E_a và ΔH là hai đại lượng hoàn toàn khác nhau: E_a luôn dương (chiều cao của rào cản), còn ΔH có thể âm hoặc dương tuỳ phản ứng toả hay thu nhiệt.

5.1.4 Catalysts and energy profiles

A **catalyst** speeds up a reaction by providing an alternative reaction pathway with a *lower* activation energy. This means more of the colliding particles already have enough energy to react, so the reaction rate increases. Crucially, a catalyst does **not** change the energy of the reactants or products, so the overall enthalpy change ΔH is exactly the same with or without the catalyst – only the height of the "hump" changes.

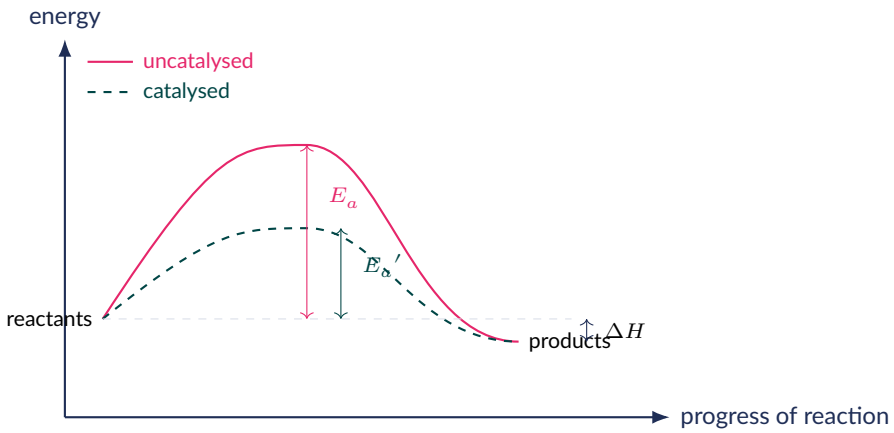

Figure 5.3. A catalyst lowers the activation energy ($E_a' < E_a$) by opening a different reaction pathway, so the reaction goes faster – but the reactants and products (and therefore ΔH) are unchanged.

VN **GIẢI THÍCH TIẾNG VIỆT**

Chất xúc tác (catalyst) làm giảm năng lượng hoạt hoá E_a bằng cách tạo ra một "con đường" phản ứng khác, giúp nhiều hạt va chạm có đủ năng lượng để phản ứng hơn → tốc độ phản ứng tăng. Tuy nhiên xúc tác **không** làm thay đổi năng lượng của chất phản ứng hay sản phẩm, nên ΔH hoàn toàn giữ nguyên – chỉ có chiều cao "đỉnh đồi" E_a là thấp xuống. Đây là lỗi học sinh hay nhầm: xúc tác không làm phản ứng toả nhiệt nhiều hơn hay ít hơn.

Ví dụ 1 · Classifying an energy profile

Magnesium burns in oxygen: $2\text{Mg} + \text{O}_2 -> 2\text{MgO}$, releasing approximately 1204 kJ per mole of reaction. Sketch and describe the shape of its energy profile.

Solution. Since energy is released, this is **exothermic**, so $\Delta H = -1204$ kJ/mol. On the profile diagram the products (2MgO) are drawn *lower* than the reactants ($2\text{Mg} + \text{O}_2$), with a hump above the reactants representing E_a (needed to ignite the magnesium ribbon). The vertical drop from reactants level to products level equals 1204 kJ.

Ví dụ 2 · Classifying an energy profile

Heating calcium carbonate causes it to decompose: $\text{CaCO}_3 -> \text{CaO} + \text{CO}_2$, with $\Delta H \approx +178$ kJ/mol. Sketch and describe the shape of its energy profile, and explain why a Bunsen burner must be kept under the solid throughout the experiment.

Solution. ΔH is positive, so this is **endothermic**: the products ($\text{CaO} + \text{CO}_2$) are drawn *higher* than the reactant CaCO_3, by 178 kJ/mol. Because the reaction constantly absorbs heat from the Bunsen flame to keep going, removing the flame stops the reaction almost immediately – unlike an exothermic reaction, which (once started) can continue releasing its own heat.

Ví dụ 3 · Catalyst effect on a profile

A certain reaction has $\Delta H = -136$ kJ/mol and an uncatalysed activation energy $E_a = 250$ kJ/mol. In the presence of a catalyst, $E_a' = 90$ kJ/mol. What is ΔH in the presence of the catalyst, and what has changed on the diagram?

Solution. A catalyst never changes ΔH, so ΔH is still -136 kJ/mol. Only the height of the hump above the reactants has fallen, from 250 kJ/mol to 90 kJ/mol; the reactants' and products' energy levels on the diagram stay exactly where they were.

(!) Lỗi thường gặp: Nhiều học sinh viết nhầm dấu của ΔH: hễ thấy phản ứng "giải phóng" năng lượng thì ΔH phải mang dấu **âm** (năng lượng rời khỏi hệ hoá học), còn phản ứng "hấp thụ" năng lượng thì ΔH mang dấu **dương**. Một câu hỏi thi thường gặp: cho biết nhiệt độ ống nghiệm tăng lên, hỏi dấu của ΔH – nhiệt độ môi trường *tăng* nghĩa là hệ đang *toả nhiệt ra* môi trường đó, vậy $\Delta H < 0$, **không phải** $\Delta H > 0$.

5.2 Measuring energy changes experimentally

5.2.1 A simple calorimetry set-up

The heat released or absorbed by a reaction can be measured experimentally using **calorimetry**: the reaction (or a burning fuel) heats (or cools) a known mass of water, whose temperature change is recorded with a thermometer.

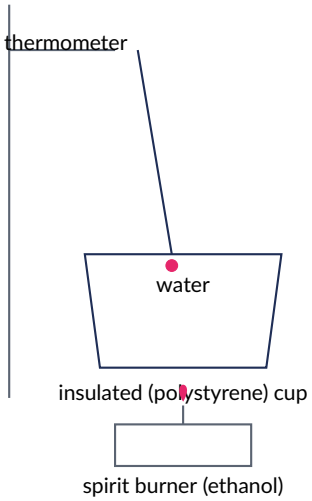

Figure 5.4. A simple calorimetry set-up: a known mass of water in an insulated cup is heated by a spirit burner. The temperature rise is measured with a thermometer, and the mass of fuel burned is found by weighing the spirit burner (with fuel) before and after burning.

Method (typical spirit-burner experiment).

1. Measure a known mass of water into the insulated cup, and record its starting temperature.
2. Weigh the spirit burner (containing the fuel) and record the mass.
3. Place the burner under the cup, light the wick, and stir the water gently while it heats.
4. Extinguish the flame once the temperature has risen by a suitable amount; record the highest temperature reached.
5. Re-weigh the burner to find the mass of fuel that was burned.

VN **GIẢI THÍCH TIẾNG VIỆT**

Nhiệt lượng kế (calorimetry) đơn giản: dùng nhiệt lượng toả ra từ một phản ứng (hoặc từ nhiên liệu đang cháy) để làm nóng một khối lượng nước đã biết, rồi đo độ tăng nhiệt độ của nước bằng nhiệt kế. Cốc xốp (polystyrene cup) đóng vai trò cách nhiệt, hạn chế thất thoát nhiệt ra ngoài không khí. Khối lượng nhiên liệu đã cháy được xác định bằng cách cân đèn cồn trước và sau khi đốt.

5.2.2 The equation $q = mc\Delta T$

The heat energy transferred to (or from) the water is calculated using

$$q = m\,c\,\Delta T$$

where q is the heat energy in joules (J), m is the mass of water in grams (g), c is the **specific heat capacity** of water, $c = 4.2$ J/g°C, and ΔT is the temperature change in °C.

Specific heat capacity of water: $c = 4.2$ J per gram per °C. This means it takes 4.2 J of energy to raise the temperature of 1 g of water by 1°C. Always use the mass of *water* (not the mass of fuel) in $q = mc\Delta T$, since it is the water that is being heated.

Ví dụ 4 · Basic $q = mc\Delta T$ calculation

250 g of water is heated from 18.0°C to 30.0°C. Calculate the heat energy absorbed by the water.

Solution. $\Delta T = 30.0 - 18.0 = 12.0^\circ$C.

$$q = mc\Delta T = 250 \times 4.2 \times 12.0 = 12\,600 \text{ J} = 12.6 \text{ kJ}.$$

Ví dụ 5 · Burning ethanol in a spirit burner

In a spirit-burner experiment, 100 g of water is heated from 20.0°C to 45.0°C. The mass of ethanol (C_2H_5OH, $M = 46$ g/mol) burned during the experiment was 0.46 g. Calculate (a) the heat released, and (b) the molar enthalpy change of combustion, ΔH_c.

Solution.

(a) $\Delta T = 45.0 - 20.0 = 25.0^\circ$C.

$$q = mc\Delta T = 100 \times 4.2 \times 25.0 = 10\,500 \text{ J} = 10.5 \text{ kJ released}.$$

(b) Moles of ethanol burned:

$$n = \frac{\text{mass}}{M} = \frac{0.46}{46} = 0.01 \text{ mol}.$$

Molar enthalpy change (heat released *per mole* of fuel):

$$\Delta H_c = -\frac{q}{n} = -\frac{10.5}{0.01} = -1050 \text{ kJ/mol}.$$

(The accepted data-book value for ethanol is about -1367 kJ/mol; the smaller experimental value reflects heat lost to the surroundings – see §5.2.4.)

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Công thức $q = mc\Delta T$ tính nhiệt lượng (q, đơn vị J) mà nước đã hấp thụ, trong đó m là khối lượng **nước** (gam), $c = 4.2$ J/g°C là nhiệt dung riêng của nước, ΔT là độ tăng nhiệt độ (°C). Sau khi có q, ta đổi sang **nhiệt mol** (kJ/mol) bằng cách chia q (đổi ra kJ) cho số mol nhiên liệu đã cháy: $\Delta H = -q/n$ (dấu âm vì phản ứng cháy là toả nhiệt). Số mol nhiên liệu tính bằng khối lượng nhiên liệu chia cho khối lượng mol M.

5.2.3 From heat released to molar enthalpy change

Enthalpy changes are always quoted **per mole** of a named substance (kJ/mol), because the amount of heat produced obviously depends on how much fuel was burned. The general procedure is:

1. Calculate $q = mc\Delta T$ (heat gained/lost by the water), in J, then convert to kJ (divide by 1000).
2. Calculate n, the moles of fuel/reactant used: $n = \dfrac{\text{mass of fuel used}}{\text{molar mass}, M}$.
3. Divide: $\Delta H = \dfrac{q \text{ (kJ)}}{n \text{ (mol)}}$, giving kJ per mole of fuel. Attach a negative sign if the reaction is exothermic (temperature of the water rose).

(!) Lỗi thường gặp: Một lỗi rất phổ biến: quên đổi từ **kJ** (nhiệt lượng của thí nghiệm cụ thể) sang **kJ/mol** (nhiệt mol chuẩn hoá). Hai đơn vị này khác nhau hoàn toàn – q tính bằng kJ chỉ đúng cho khối lượng nhiên liệu cụ thể đã cháy trong thí nghiệm đó, còn ΔH tính bằng kJ/mol mới có thể đem so sánh giữa các nhiên liệu khác nhau hoặc so với giá trị trong sách dữ liệu. Luôn luôn chia q cho số mol trước khi báo cáo ΔH.

5.2.4 Sources of experimental error (Supplement)

(Supplement) Experimental values of ΔH from simple calorimetry are almost always *smaller in magnitude* than the accepted (data-book) value, mainly because of heat loss. Common sources of error include:

- **Heat loss to the surroundings** – heat radiates from the sides of the cup and the flame heats the surrounding air, not just the water; using a lid with a small hole for the thermometer, and an insulating draft shield, reduces this.
- **Incomplete combustion** – if the flame is starved of oxygen it produces soot and carbon monoxide instead of only CO_2 and H_2O, releasing less energy than complete combustion would.
- **Evaporation of the fuel** – some fuel may evaporate from the wick without burning, making the mass of fuel "burned" appear larger than the mass that actually reacted to release heat.
- **Heat capacity of the apparatus** – the container and thermometer itself absorb some heat, which is not accounted for by $q = mc\Delta T$ (which only considers the water).
- **Non-continuous stirring / temperature not fully equilibrated** – can lead to an inaccurate maximum-temperature reading.

Because all of these losses reduce the amount of heat that actually reaches the water, experimental values of $|\Delta H_c|$ calculated this way are typically *lower* than the true value – they should be reported as approximate, not exact.

VN **GIẢI THÍCH TIẾNG VIỆT**

(Supplement) Giá trị ΔH đo được từ thí nghiệm đơn giản (đèn cồn, cốc xốp) hầu như luôn **nhỏ hơn** giá trị thật trong sách dữ liệu, do nhiệt bị thất thoát: toả ra không khí xung quanh thay vì truyền hết vào nước, cháy không hoàn toàn (sinh khói/CO thay vì cháy hết), nhiên liệu bay hơi mà không cháy, hoặc chính cốc/nhiệt kế cũng hấp thụ một phần nhiệt. Đây là lý do các đề thi thường hỏi "tại sao giá trị thực nghiệm nhỏ hơn giá trị lý thuyết" – câu trả lời luôn xoay quanh sự thất thoát nhiệt.

5.3 Bond energy calculations

(Supplement) A chemical reaction involves breaking bonds in the reactants and forming new bonds in the products. **Bond energy** (bond enthalpy) is the energy needed to break one mole of a particular covalent bond in the gas phase.

Breaking vs. forming bonds

Breaking bonds *requires* an input of energy – it is always **endothermic** (energy in).
Forming new bonds *releases* energy – it is always **exothermic** (energy out).

The overall enthalpy change of a reaction is the balance between these two opposing energy changes:

$$\Delta H = \Sigma(\text{bond energies of bonds } \textit{broken}) - \Sigma(\text{bond energies of bonds } \textit{formed}).$$

If more energy is released forming the new bonds than was needed to break the old ones, the reaction is exothermic ($\Delta H < 0$); if more energy is needed to break the old bonds than is released forming new ones, the reaction is endothermic ($\Delta H > 0$).

VN **GIẢI THÍCH TIẾNG VIỆT**

(Supplement) Trong bất kỳ phản ứng hoá học nào, các liên kết trong chất phản ứng bị **phá vỡ** (cần năng lượng, thu nhiệt) và các liên kết mới trong sản phẩm được **hình thành**

(giải phóng năng lượng, toả nhiệt). Công thức: $\Delta H = \Sigma(\text{năng lượng liên kết bị phá vỡ}) - \Sigma(\text{năng lượng liên kết được tạo thành})$. Nếu năng lượng toả ra khi tạo liên kết mới *lớn hơn* năng lượng cần để phá vỡ liên kết cũ thì phản ứng toả nhiệt ($\Delta H < 0$); ngược lại là thu nhiệt ($\Delta H > 0$).

(!) Lỗi thường gặp: **(Supplement)** Rất nhiều học sinh nhớ ngược chiều: nghĩ rằng **phá vỡ** liên kết là toả nhiệt. Hãy nhớ theo nghĩa vật lý: để tách hai nguyên tử đang liên kết chặt với nhau, ta phải *bơm năng lượng vào* – giống như phải tốn công để kéo hai nam châm đang hút nhau ra xa – vậy phá vỡ liên kết luôn **thu nhiệt** (energy IN). Ngược lại, khi hai nguyên tử tự do kết hợp lại thành liên kết mới, hệ *giải phóng* năng lượng ra ngoài – hình thành liên kết luôn **toả nhiệt** (energy OUT).

5.3.1 Bond energies used in this chapter

(Supplement) The table below lists the average bond energies used in the worked examples and practice questions that follow.

Bond	Energy (kJ/mol)	Bond	Energy (kJ/mol)
H – H	436	C – H	413
Cl – Cl	242	C – C	347
H – Cl	431	C = C	612
N ≡ N	945	C = O (in CO_2)	805
N – H	391		
O = O	498		
O – H	463		

5.3.2 Worked calculations

Ví dụ 6 · $H_2 + Cl_2$

Calculate ΔH for $H_2 + Cl_2 -> 2HCl$.

Bonds broken: 1 H – H + 1 Cl – Cl $= 436 + 242 = 678$ kJ.
Bonds formed: 2 H – Cl $= 2 \times 431 = 862$ kJ.

$$\Delta H = 678 - 862 = -184 \text{ kJ/mol (exothermic).}$$

Ví dụ 7 · Haber process

Calculate ΔH for $N_2 + 3H_2 -> 2NH_3$.

Bonds broken: 1 N ≡ N + 3 H – H $= 945 + 3(436) = 945 + 1308 = 2253$ kJ.
Bonds formed: 2 NH_3 molecules, each with 3 N – H bonds $= 6 \times 391 = 2346$ kJ.

$$\Delta H = 2253 - 2346 = -93 \text{ kJ/mol (exothermic).}$$

Ví dụ 8 · Combustion of methane

Calculate ΔH for $CH_4 + 2O_2 -> CO_2 + 2H_2O$.

Bonds broken: 4 C – H + 2 O = O $= 4(413) + 2(498) = 1652 + 996 = 2648$ kJ.
Bonds formed: 2 C = O (in CO_2) + 4 O – H (in $2H_2O$) $= 2(805) + 4(463) = 1610 + 1852 = 3462$

kJ.

$$\Delta H = 2648 - 3462 = -814 \text{ kJ/mol (exothermic).}$$

Ví dụ 9 · Combustion of hydrogen

Calculate ΔH for $2H_2 + O_2 -> 2H_2O$.
Bonds broken: 2 H − H + 1 O = O $= 2(436) + 498 = 872 + 498 = 1370$ kJ.
Bonds formed: 2 H_2O molecules, each with 2 O − H bonds $= 4 \times 463 = 1852$ kJ.

$$\Delta H = 1370 - 1852 = -482 \text{ kJ/mol (strongly exothermic).}$$

VN **GIẢI THÍCH TIẾNG VIỆT**
(Supplement) Cách trình bày một bài toán năng lượng liên kết: (1) liệt kê từng loại liên kết bị phá vỡ ở chất phản ứng và cộng năng lượng của chúng lại; (2) liệt kê từng loại liên kết được tạo thành ở sản phẩm và cộng lại; (3) lấy tổng (1) trừ tổng (2). Luôn đếm **đúng số lượng** mỗi loại liên kết theo công thức phân tử – ví dụ NH_3 có 3 liên kết N − H, nên $2NH_3$ có 6 liên kết N − H, không phải 3.

5.4 Fuels and combustion

5.4.1 Complete and incomplete combustion of hydrocarbons

Complete combustion occurs when a hydrocarbon burns in a plentiful supply of oxygen, producing only carbon dioxide and water:

$$C_3H_8 + 5O_2 -> 3CO_2 + 4H_2O \qquad \text{(propane, complete combustion)}$$

$$2C_4H_{10} + 13O_2 -> 8CO_2 + 10H_2O \qquad \text{(butane, complete combustion)}$$

Incomplete combustion occurs when the oxygen supply is limited. Instead of CO_2, some or all of the carbon forms poisonous **carbon monoxide**, CO, and/or unburnt **soot** (carbon particles):

$$2CH_4 + 3O_2 -> 2CO + 4H_2O \qquad \text{(incomplete: carbon monoxide)}$$

$$CH_4 + O_2 -> C + 2H_2O \qquad \text{(incomplete: soot)}$$

Both complete and incomplete combustion are exothermic, but incomplete combustion always releases *less* energy per mole of fuel than complete combustion, because not all the available chemical energy in the carbon has been released.

Danger of CO: carbon monoxide is a colourless, odourless, toxic gas. It binds strongly to haemoglobin in red blood cells, preventing oxygen transport around the body – this is why gas appliances need adequate ventilation and carbon monoxide detectors.

VN **GIẢI THÍCH TIẾNG VIỆT**
Đốt cháy **hoàn toàn** (đủ oxy) một hydrocarbon chỉ tạo ra CO_2 và H_2O. Đốt cháy **không hoàn toàn** (thiếu oxy) tạo ra khí CO độc (không màu, không mùi, gắn chặt vào hemoglobin trong máu ngăn cản vận chuyển oxy) và/hoặc bồ hóng (carbon chưa cháy hết). Đốt không hoàn toàn luôn giải phóng **ít năng lượng hơn** so với đốt hoàn toàn từ cùng một lượng nhiên liệu.

5.4.2 Comparing energy values of fuels

The **energy value** of a fuel is the amount of energy released when a given amount of it burns completely, usually quoted in kJ per gram (kJ/g) or kJ per mole (kJ/mol). Calorimetry experiments (§5.2) let us compare fuels directly.

Ví dụ 10 · Comparing methanol and ethanol

Two calorimetry experiments each heat 100 g of water.
Methanol (CH_3OH, $M = 32$ g/mol): 0.32 g burned, water rises by 15.0°C.

$$q = 100 \times 4.2 \times 15.0 = 6300 \text{ J} = 6.3 \text{ kJ}; \qquad n = \frac{0.32}{32} = 0.01 \text{ mol}$$

$$\text{Energy value} = \frac{6.3 \text{ kJ}}{0.32 \text{ g}} = 19.7 \text{ kJ/g}; \qquad \Delta H_c = -\frac{6.3}{0.01} = -630 \text{ kJ/mol}.$$

Ethanol (C_2H_5OH, $M = 46$ g/mol): 0.46 g burned, water rises by 25.0°C (as in Example 5).

$$q = 100 \times 4.2 \times 25.0 = 10\,500 \text{ J} = 10.5 \text{ kJ}; \qquad n = \frac{0.46}{46} = 0.01 \text{ mol}$$

$$\text{Energy value} = \frac{10.5 \text{ kJ}}{0.46 \text{ g}} = 22.8 \text{ kJ/g}; \qquad \Delta H_c = -\frac{10.5}{0.01} = -1050 \text{ kJ/mol}.$$

Conclusion. In this experiment, ethanol released both more energy per mole *and* more energy per gram than methanol. (Both experimental values are lower than the accepted data-book values, -715 and -1367 kJ/mol respectively, because of heat loss – see §5.2.4.)

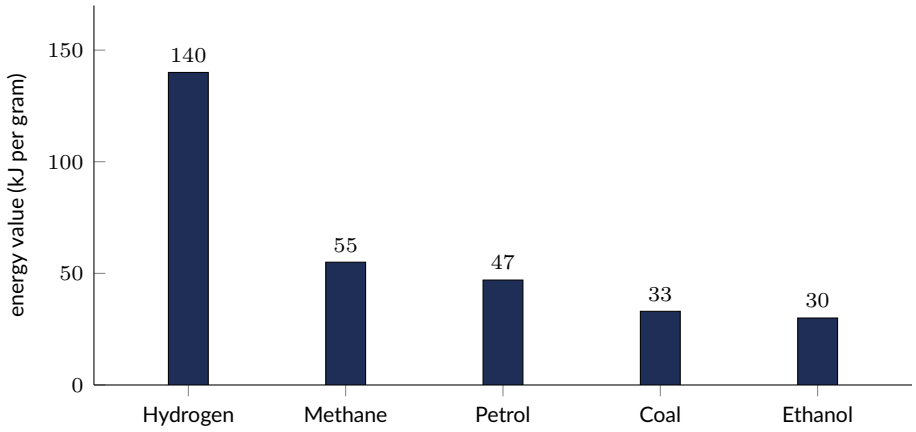


Figure 5.5. Typical/approximate energy values of common fuels (kJ released per gram burned completely). Hydrogen has by far the highest energy value per gram – one reason it is attractive as a rocket and vehicle fuel despite the practical difficulties of storing it (§5.5.3).

VN GIẢI THÍCH TIẾNG VIỆT

Để so sánh nhiên liệu, ta tính **giá trị năng lượng** theo kJ/gam (chia q cho khối lượng nhiên liệu đã cháy) và/hoặc kJ/mol (chia q cho số mol). Hai cách so sánh này có thể cho thứ tự khác nhau, vì khối lượng mol của các nhiên liệu khác nhau. Hydro có giá trị năng lượng theo gam cao vượt trội so với mọi nhiên liệu hoá thạch hay cồn, do phân tử rất nhẹ nhưng phản ứng cháy toả rất nhiều năng lượng.

Bài tập luyện tập

According to Figure 5.5, which of the five fuels shown releases the *least* energy per gram when burned completely?

(A) Hydrogen
(B) Methane
(C) Coal
(D) Ethanol

Lời giải chi tiết

Reading the bar chart: hydrogen ≈ 140, methane ≈ 55, petrol ≈ 47, coal ≈ 33, ethanol ≈ 30 kJ/g. The shortest bar is ethanol. **(D)**.

Bài tập luyện tập

Using $\Delta H = -482$ kJ/mol for $2H_2 + O_2 -> 2H_2O$ (Example 9), calculate the energy value of hydrogen in kJ per gram, and comment on why it is so much higher than that of methane (which has a similar-sized ΔH per mole of fuel).

Lời giải chi tiết

$\Delta H = -482$ kJ/mol of reaction corresponds to 2 mol of H_2, so per mole of H_2: $-482/2 = -241$ kJ/mol. The molar mass of H_2 is only 2 g/mol, so

$$\text{energy value} = \frac{241 \text{ kJ/mol}}{2 \text{ g/mol}} = 120.5 \text{ kJ/g}.$$

Methane releases a broadly comparable amount of energy *per mole* (-814 kJ/mol, Example 8), but its molar mass (16 g/mol) is 8 times larger than hydrogen's, so dividing by a much bigger M gives a much smaller value per gram ($814/16 \approx 51$ kJ/g). Hydrogen's advantage in kJ/g comes from its very low molar mass, not from an unusually large ΔH per mole.

5.4.3 Advantages and disadvantages of common fuels

Fuel	Advantages	Disadvantages
Coal	Cheap, abundant reserves, high energy value	High CO_2 and SO_2 emissions; solid, hard to transport/store; non-renewable
Natural gas (CH_4)	Burns cleanly (less soot/SO_2 than coal), easy to pipe, high energy value	Still releases CO_2; non-renewable; explosion/leak risk
Petrol/diesel	High energy density, existing infrastructure	CO_2, CO, unburnt hydrocarbons, particulates; non-renewable
Ethanol (biofuel)	Can be renewable (from crops); roughly carbon-neutral overall	Lower energy value than petrol; competes with food crop land
Hydrogen	Only product is water; very high energy value per gram	Costly to produce/store; needs new infrastructure (§5.5.3)

Bài tập luyện tập

Which of the following processes is *exothermic*?

(A) Thermal decomposition of copper(II) carbonate

(B) Photosynthesis

(C) Neutralisation of hydrochloric acid by sodium hydroxide solution

(D) Evaporation of water

Lời giải chi tiết

Neutralisation, $\mathrm{HCl} + \mathrm{NaOH} -> \mathrm{NaCl} + \mathrm{H_2O}$, releases heat – the test tube feels warmer. Thermal decomposition and photosynthesis both absorb energy (endothermic); evaporation is a physical change that absorbs energy, not a chemical reaction. **(C)**.

Bài tập luyện tập

250 g of water is heated from 18.0°C to 30.0°C by an electric immersion heater. Calculate the heat energy transferred to the water, in kJ.

Lời giải chi tiết

$\Delta T = 30.0 - 18.0 = 12.0^\circ$C.

$$q = mc\Delta T = 250 \times 4.2 \times 12.0 = 250 \times 4.2 = 1050; \quad 1050 \times 12.0 = 12\,600 \text{ J} = 12.6 \text{ kJ}.$$

Bài tập luyện tập

On an energy profile diagram, adding a catalyst to a reaction:

(A) Lowers E_a and makes ΔH more negative

(B) Lowers E_a but leaves ΔH unchanged

(C) Leaves E_a unchanged but lowers ΔH

(D) Raises both E_a and ΔH

Lời giải chi tiết

A catalyst opens an alternative pathway with a lower activation energy, so E_a falls; but the energy of the reactants and products is unaffected, so ΔH is exactly the same. **(B)**.

Bài tập luyện tập

A student burns propan-1-ol ($\mathrm{C_3H_7OH}$, $M = 60$ g/mol) under 150 g of water. The mass of propanol burned is 0.30 g, and the water temperature rises by 15.0°C. Calculate the molar enthalpy change of combustion.

Lời giải chi tiết

$$q = mc\Delta T = 150 \times 4.2 \times 15.0 = 630 \times 15.0 = 9450 \text{ J} = 9.45 \text{ kJ}.$$

$$n = \frac{0.30}{60} = 0.005 \text{ mol}.$$

$$\Delta H_c = -\frac{q}{n} = -\frac{9.45}{0.005} = -1890 \text{ kJ/mol}.$$

Bài tập luyện tập

(Supplement) Which change to the apparatus in Figure 5.4 would most reduce heat lost to the surroundings during the experiment?

(A) Using an uninsulated metal cup instead of the polystyrene cup

(B) Placing a lid with a small hole for the thermometer on top of the cup

(C) Moving the burner further away from the base of the cup

(D) Using a larger volume of water

Lời giải chi tiết

A lid traps rising heat that would otherwise escape from the top of the cup (a major site of heat loss), while still allowing the thermometer through a small hole. A metal cup would conduct heat away faster (worse); moving the flame away wastes even more heat before it reaches the cup; using more water only makes the temperature rise smaller for the same heat, it does not reduce heat *lost*. **(B)**.

Bài tập luyện tập

A student dissolves 4.0 g of ammonium nitrate (NH_4NO_3, $M = 80$ g/mol) in 50 g of water. The temperature of the water falls from 25.0°C to 15.0°C. Calculate the molar enthalpy change of dissolving, and state its sign.

Lời giải chi tiết

$$\Delta T = 25.0 - 15.0 = 10.0^\circ\text{C}; \qquad q = mc\Delta T = 50 \times 4.2 \times 10.0 = 2100\ \text{J} = 2.1\ \text{kJ}.$$

$$n = \frac{4.0}{80} = 0.05\ \text{mol}; \qquad \Delta H = +\frac{2.1}{0.05} = +42\ \text{kJ/mol}.$$

The temperature of the water *fell*, so the dissolving process absorbed heat from the water: it is **endothermic**, so ΔH is positive, $+42$ kJ/mol.

Bài tập luyện tập

(Supplement) Calculate ΔH for the reverse of the $H_2 + Cl_2$ reaction, i.e. $2HCl -> H_2 + Cl_2$, using the bond energies in §5.3.1.

Lời giải chi tiết

Bonds broken: 2 H − Cl $= 2 \times 431 = 862$ kJ.
Bonds formed: 1 H − H + 1 Cl − Cl $= 436 + 242 = 678$ kJ.

$$\Delta H = 862 - 678 = +184\ \text{kJ/mol}.$$

This is the exact negative of ΔH for the forward reaction (-184 kJ/mol) – reversing a reaction always reverses the sign of ΔH.

Bài tập luyện tập

(Supplement) Calculate ΔH for the decomposition of ammonia, $2NH_3 -> N_2 + 3H_2$, using the bond energies in §5.3.1.

Lời giải chi tiết

Bonds broken: 2 NH_3, each with 3 N − H bonds $= 6 \times 391 = 2346$ kJ.
Bonds formed: 1 N ≡ N + 3 H − H $= 945 + 3(436) = 945 + 1308 = 2253$ kJ.

$$\Delta H = 2346 - 2253 = +93 \text{ kJ/mol}.$$

Again this is the reverse of the Haber process (-93 kJ/mol), confirming that decomposing ammonia back into its elements is endothermic.

Bài tập luyện tập

(Supplement) Calculate ΔH for the complete combustion of ethane, $2C_2H_6 + 7O_2 -> 4CO_2 + 6H_2O$. (Each C_2H_6 molecule contains 1 C − C bond and 6 C − H bonds.) Use the bond energies in §5.3.1.

Lời giải chi tiết

Bonds broken: 2 C_2H_6 molecules × (1 C − C + 6 C − H), plus 7 O = O:

$$2 \times [347 + 6(413)] + 7(498) = 2 \times [347 + 2478] + 3486 = 2(2825) + 3486 = 5650 + 3486 = 9136 \text{ kJ}.$$

Bonds formed: 4 CO_2 (each 2 C = O) + 6 H_2O (each 2 O − H):

$$4 \times 2 \times 805 + 6 \times 2 \times 463 = 6440 + 5556 = 11\,996 \text{ kJ}.$$

$\Delta H = 9136 - 11\,996 = -2860$ kJ per equation (2 mol ethane), i.e. -1430 kJ per mole of ethane.

Bài tập luyện tập

Which products form when a hydrocarbon fuel burns in a *limited* supply of oxygen?

(A) Only CO_2 and H_2O

(B) CO_2 and H_2

(C) Carbon monoxide (CO) and/or soot (carbon), as well as H_2O

(D) Only H_2O

Lời giải chi tiết

With insufficient oxygen, not all the carbon can be oxidised fully to CO_2; some forms toxic carbon monoxide, CO, and/or unburnt carbon (soot). Water is still formed since hydrogen still reacts with oxygen. **(C)**.

Bài tập luyện tập

Balance the equation for the complete combustion of propane, $C_3H_8 + O_2 -> CO_2 + H_2O$, and state whether the reaction is exothermic or endothermic.

Lời giải chi tiết

Balancing carbon: 3 CO_2. Balancing hydrogen: 4 H_2O (8 H atoms). Balancing oxygen: right-hand side has $3 \times 2 + 4 \times 1 = 6 + 4 = 10$ O atoms, so 5 O_2 are needed on the left.

$$C_3H_8 + 5O_2 -> 3CO_2 + 4H_2O.$$

Combustion reactions always release energy to the surroundings, so this is **exothermic** ($\Delta H <$

0).

Bài tập luyện tập

Two alcohols are tested by burning them under 100 g of water each. **Propan-1-ol** ($M = 60$): 0.30 g burned, $\Delta T = 15.0^\circ$C. **Butan-1-ol** ($M = 74$): 0.37 g burned, $\Delta T = 18.0^\circ$C. Calculate the energy value in kJ/g and kJ/mol for each alcohol, and state which released more energy per gram, and which released more energy per mole, in this experiment.

Lời giải chi tiết

Propan-1-ol: $q = 100 \times 4.2 \times 15.0 = 6300$ J $= 6.3$ kJ. $n = 0.30/60 = 0.005$ mol.

$$\text{kJ/g} = \frac{6.3}{0.30} = 21.0 \text{ kJ/g}; \qquad \text{kJ/mol} = \frac{6.3}{0.005} = 1260 \text{ kJ/mol}.$$

Butan-1-ol: $q = 100 \times 4.2 \times 18.0 = 7560$ J $= 7.56$ kJ. $n = 0.37/74 = 0.005$ mol.

$$\text{kJ/g} = \frac{7.56}{0.37} = 20.4 \text{ kJ/g}; \qquad \text{kJ/mol} = \frac{7.56}{0.005} = 1512 \text{ kJ/mol}.$$

Comparison: butan-1-ol released more energy *per mole* ($1512 > 1260$ kJ/mol), but propan-1-ol released slightly more energy *per gram* in this experiment ($21.0 > 20.4$ kJ/g) – a reminder that rankings by kJ/mol and kJ/g need not agree, and that both figures carry experimental heat-loss error.

Bài tập luyện tập

A reaction has $\Delta H = -92$ kJ/mol. The total bond energy of the bonds broken in the reactants is 1000 kJ/mol. Calculate the total bond energy of the bonds formed in the products.

Lời giải chi tiết

Rearranging $\Delta H = \Sigma(\text{broken}) - \Sigma(\text{formed})$:

$$\Sigma(\text{formed}) = \Sigma(\text{broken}) - \Delta H = 1000 - (-92) = 1092 \text{ kJ/mol}.$$

(Check: $1000 - 1092 = -92$ kJ/mol $= \Delta H$.)

Bài tập luyện tập

42 kJ of heat is released into 500 g of water, initially at 20.0°C. Calculate the final temperature of the water.

Lời giải chi tiết

$$\Delta T = \frac{q}{mc} = \frac{42\,000}{500 \times 4.2} = \frac{42\,000}{2100} = 20.0^\circ\text{C}.$$

Final temperature $= 20.0 + 20.0 = 40.0^\circ$C.

Bài tập luyện tập

A student burns 0.02 mol of a fuel and measures $q = 12.6$ kJ released. He reports $\Delta H = -12.6$ kJ/mol. Explain the error and give the correct value.

Lời giải chi tiết

The student has confused the heat released in this particular experiment (12.6 kJ, which depends on how much fuel was burned) with the molar enthalpy change (ΔH, which is per mole and independent of the sample size). He forgot to divide by the number of moles.

$$\Delta H = -\frac{q}{n} = -\frac{12.6}{0.02} = -630 \text{ kJ/mol}.$$

Bài tập luyện tập

A forward reaction has $E_a = 250$ kJ/mol and $\Delta H = -100$ kJ/mol. Determine the activation energy of the *reverse* reaction.

Lời giải chi tiết

On the energy profile, the hump sits 250 kJ/mol above the reactants. Since the reaction is exothermic, the products lie 100 kJ/mol *below* the reactants, so the hump lies $250 + 100 = 350$ kJ/mol above the products.

$$E_a(\text{reverse}) = E_a(\text{forward}) - \Delta H(\text{forward}) = 250 - (-100) = 350 \text{ kJ/mol}.$$

5.5 Hydrogen as a fuel: the hydrogen-oxygen fuel cell

5.5.1 The fuel-cell reaction

Hydrogen is an exceptionally clean fuel: its complete combustion produces *only* water,

$$2H_2 + O_2 -> 2H_2O,$$

with no carbon dioxide, carbon monoxide, soot, or hydrocarbon pollutants. Instead of simply burning hydrogen to release heat, this same overall reaction can be carried out in a **hydrogen-oxygen fuel cell**, which generates **electricity directly** at the electrodes rather than heat – hydrogen and oxygen are fed in continuously, and electrical energy plus water are produced continuously, without a flame.

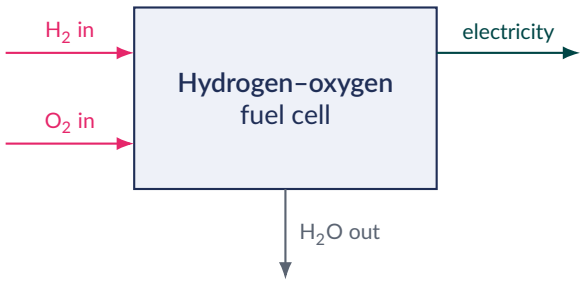


Figure 5.6. A hydrogen-oxygen fuel cell: hydrogen and oxygen combine at the electrodes to produce electrical energy directly, with water as the only chemical product ($2H_2 + O_2 -> 2H_2O$) – there is no flame and no combustion.

VN **GIẢI THÍCH TIẾNG VIỆT**

Pin nhiên liệu hydro–oxy (hydrogen-oxygen fuel cell) sử dụng đúng phản ứng

$2H_2 + O_2 -> 2H_2O$, nhưng thay vì đốt cháy để lấy nhiệt, phản ứng xảy ra tại các điện cực để sinh ra **dòng điện trực tiếp**. Khí H_2 và O_2 được bơm liên tục vào pin, và pin liên tục tạo ra điện cùng với nước – sản phẩm hoá học duy nhất – mà không hề có ngọn lửa.

5.5.2 Advantages over combustion engines

Ví dụ 11 · Fuel cell vs. petrol engine

Compare a hydrogen fuel cell vehicle with a conventional petrol-engine vehicle in terms of chemical products and pollution.

Solution. The petrol engine burns a hydrocarbon fuel, producing CO_2 (a greenhouse gas), and – especially under incomplete combustion – CO, unburnt hydrocarbons, soot, and oxides of nitrogen from the high-temperature combustion of air. The hydrogen fuel cell reaction, $2H_2 + O_2 -> 2H_2O$, produces *only* water. It is also generally more efficient, because it converts chemical energy directly into electrical energy without first converting it to heat and then to mechanical motion (each conversion step loses energy, typically as waste heat) – and it runs quietly, with no combustion noise or vibration.

VN **GIẢI THÍCH TIẾNG VIỆT**

So với động cơ đốt trong dùng xăng, pin nhiên liệu hydro có ưu điểm: sản phẩm duy nhất là nước (không CO_2, không CO, không bồ hóng, không oxit nitơ); hiệu suất chuyển hoá năng lượng cao hơn vì không phải trải qua bước trung gian đốt cháy → nhiệt → chuyển động cơ học (mỗi bước chuyển đổi đều thất thoát năng lượng dưới dạng nhiệt); và hoạt động êm, không rung động do không có quá trình đốt cháy.

5.5.3 Limitations (Supplement)

(Supplement) Despite these advantages, hydrogen fuel cells are not yet used as widely as petrol/diesel engines, mainly because of practical and economic limitations:

- **Production cost:** most hydrogen today is made by steam-reforming natural gas, a process that itself releases CO_2; producing hydrogen by electrolysis of water using renewable electricity is cleaner but currently more expensive.
- **Storage:** hydrogen gas has a very low density, so storing enough of it for a useful driving range requires very high-pressure tanks or extremely cold liquefaction, both of which add cost, weight, and complexity to a vehicle.
- **Infrastructure:** there are far fewer hydrogen refuelling stations than petrol stations, making refuelling less convenient.
- **Safety:** hydrogen is highly flammable and diffuses easily, requiring careful engineering to prevent leaks.

VN **GIẢI THÍCH TIẾNG VIỆT**

(Supplement) Hạn chế hiện nay của hydro làm nhiên liệu: phần lớn hydro được sản xuất từ khí thiên nhiên (steam reforming), quá trình này vẫn thải ra CO_2, nên hydro chỉ thực sự "sạch" nếu được sản xuất bằng điện phân nước dùng điện tái tạo (hiện vẫn đắt hơn); hydro có mật độ rất thấp nên cần bồn chứa áp suất cao hoặc hoá lỏng ở nhiệt độ cực thấp, làm tăng chi phí và khối lượng xe; hạ tầng trạm nạp hydro còn rất ít so với trạm xăng; và hydro dễ cháy nổ nên cần thiết kế an toàn cẩn thận.

Bài tập luyện tập

What is the main advantage of a hydrogen-oxygen fuel cell over burning a hydrocarbon fuel in a car engine?

(A) It is currently cheaper to produce hydrogen than petrol

(B) The only product is water – no CO_2, CO, or particulates are released

(C) Hydrogen has a higher boiling point than petrol

(D) It does not require oxygen to react

Lời giải chi tiết

$2H_2 + O_2 -> 2H_2O$ produces only water, avoiding the greenhouse gases and pollutants (CO_2, CO, soot, oxides of nitrogen) released when hydrocarbon fuels are burned. **(B)**.

Bài tập luyện tập

(Supplement) Which of the following is currently the *most significant* practical barrier to the widespread use of hydrogen fuel cell vehicles?

(A) Hydrogen does not react with oxygen at room temperature

(B) Storing enough hydrogen on board requires high-pressure or cryogenic tanks, and refuelling infrastructure is limited

(C) Fuel cells release more carbon dioxide than petrol engines

(D) Hydrogen fuel cells cannot generate enough electricity to power a motor

Lời giải chi tiết

Hydrogen's very low density makes on-board storage (high-pressure or liquefied tanks) costly and bulky, and the network of hydrogen refuelling stations is currently far smaller than the petrol-station network. Fuel cells in fact release no CO_2 at the point of use, and they can generate ample electricity to drive a motor. **(B)**.

Bài tập luyện tập

State one advantage and one disadvantage of using hydrogen, rather than petrol, as a vehicle fuel.

Lời giải chi tiết

Advantage: using hydrogen (in combustion or a fuel cell) produces only water as a product, so it causes no CO_2 emissions or air pollution at the point of use. **Disadvantage:** hydrogen is expensive and energy-intensive to produce and store safely (high-pressure or cryogenic tanks), and refuelling infrastructure is far less widespread than for petrol. (Any one valid advantage and one valid disadvantage is acceptable.)

5.6 Renewable and non-renewable energy sources (Supplement)

(Supplement) Fuels and other energy sources can be classified as **renewable** (naturally replenished on a human timescale, effectively inexhaustible) or **non-renewable** (formed over millions of years and used up far faster than they can reform).

Renewable	Non-renewable
Solar (sunlight)	Coal
Wind	Crude oil / petroleum products
Hydroelectric (falling/flowing water)	Natural gas
Geothermal	Nuclear fuel (uranium) – finite, though not a fossil fuel
Biofuels (e.g. ethanol from crops)	

(Supplement) **Fossil fuels** (coal, oil, natural gas) release large amounts of energy per kilogram and existing infrastructure is built around them, but burning them adds "new" carbon dioxide (locked away for millions of years) to the atmosphere, contributing to the greenhouse effect, and they will eventually run out. Renewable sources do not run out and (with the exception of biofuel combustion) release no CO_2 during energy generation itself, but they are often less concentrated (need large solar panel/wind turbine areas), depend on weather/location, and can have a higher initial cost to set up.

VN GIẢI THÍCH TIẾNG VIỆT

(Supplement) Nguồn năng lượng **tái tạo** (renewable) – như mặt trời, gió, thuỷ điện, địa nhiệt, nhiên liệu sinh học – được bổ sung liên tục trong tự nhiên nên gần như không cạn kiệt. Nguồn **không tái tạo** (non-renewable) – than đá, dầu mỏ, khí thiên nhiên (nhiên liệu hoá thạch) và nhiên liệu hạt nhân – hình thành qua hàng triệu năm nên đang bị khai thác nhanh hơn nhiều tốc độ tái tạo, và cuối cùng sẽ cạn kiệt. Nhiên liệu hoá thạch toả nhiều năng lượng trên một kg và hạ tầng sẵn có, nhưng thải thêm CO_2 (vốn bị khoá trong lòng đất hàng triệu năm) vào khí quyển, góp phần vào hiệu ứng nhà kính; năng lượng tái tạo không cạn kiệt và (trừ đốt sinh khối) hầu như không thải CO_2 khi phát điện, nhưng thường kém tập trung hơn, phụ thuộc thời tiết/vị trí địa lý, và chi phí đầu tư ban đầu cao hơn.

Bài tập luyện tập

(Supplement) Which of the following is a renewable energy source?

(A) Coal
(B) Natural gas
(C) Wind
(D) Crude oil

Lời giải chi tiết

Wind is continuously replenished by natural weather patterns and will not run out on a human timescale. Coal, natural gas, and crude oil are all fossil fuels, formed over millions of years and used up far faster than they reform – they are non-renewable. **(C)**.

Bài tập luyện tập

(Supplement) Explain why burning ethanol produced from sugar cane is often described as roughly "carbon-neutral" overall, whereas burning petrol is not.

Lời giải chi tiết

The sugar cane used to make the ethanol absorbed carbon dioxide from the atmosphere (via photosynthesis) as it grew; when the ethanol is later burned, it releases approximately that same amount of CO_2 back into the atmosphere, so there is little *net* addition of CO_2 over the growth-and-burning cycle. Petrol, by contrast, is made from crude oil that had locked its carbon away underground for millions of years; burning it releases CO_2 that was not part of the recent atmospheric cycle, so it represents a net *addition* of CO_2 to the atmosphere.

Bài tập luyện tập

(Supplement) Give one advantage and one disadvantage of generating electricity from wind turbines compared with a coal-fired power station.

Lời giải chi tiết

Advantage: wind is renewable and free, and generating electricity from it releases no CO_2, SO_2, or particulates during operation. **Disadvantage:** wind is not always available (intermittent, depends on weather), so it cannot supply a constant, reliable output on demand the way a coal-fired station can, and wind farms require large areas of land or sea to generate a comparable amount of power. (Any one valid advantage and disadvantage is acceptable.)

Bài tập luyện tập

(Supplement) Uranium, used as a nuclear fuel, is best classified as:

(A) Renewable, because nuclear reactions constantly create new uranium

(B) Non-renewable, because natural uranium deposits took geological ages to form and exist in a finite amount

(C) Neither renewable nor non-renewable, since uranium is not burned in air

(D) Renewable, because it does not release CO_2 when used

Lời giải chi tiết

The classification renewable/non-renewable is about whether a resource can be replenished on a human timescale, not about whether it is combusted or whether it releases CO_2. Uranium ore took geological ages to form in the Earth's crust and exists only in a fixed, finite quantity, so it is **non-renewable** – even though burning is not involved and, unlike fossil fuels, using it does not directly release CO_2. **(B)**.

Chemical Reactions: Rate, Reversibility and Redox

Mục tiêu Unit: Thuyết va chạm và các yếu tố ảnh hưởng tốc độ phản ứng (nồng độ, nhiệt độ, diện tích bề mặt, xúc tác); các phương pháp đo tốc độ phản ứng trong phòng thí nghiệm và phân tích đồ thị tốc độ; cơ chế hoạt động của chất xúc tác; phản ứng thuận nghịch và cân bằng động; nguyên lý Le Chatelier áp dụng cho quá trình Haber và quá trình Contact (Supplement); phản ứng oxi hoá–khử theo hai cách định nghĩa (electron và oxygen/hydrogen); số oxi hoá và cách dùng số oxi hoá để xác định chất bị oxi hoá/khử (Supplement).

6.1 Collision theory and rate of reaction

The **rate of a chemical reaction** measures how quickly reactants are converted into products — for example, how fast a gas is produced, a precipitate forms, or a colour fades. **Collision theory** explains why reactions proceed at the rates they do, and why changing the conditions changes those rates.

For two particles to react when they collide, two conditions must *both* be satisfied:

1. The particles must actually collide with one another.
2. The collision must have enough energy — at least the **activation energy**, E_a (Chapter 5) — and the particles must be orientated correctly relative to each other.

A collision that meets both conditions is called a **successful** (or *effective*) collision; only a small fraction of all collisions are successful, because most colliding particles do not carry enough kinetic energy at the moment of impact. The rate of reaction is proportional to the frequency of successful collisions per unit time:

$$\text{rate} \propto (\text{frequency of collisions}) \times (\text{fraction of collisions that are successful}).$$

Any change in conditions that increases either of these two quantities increases the rate of reaction.

Khái niệm cốt lõi

Collision theory, in short: particles react only when they collide with (i) sufficient energy ($\geq E_a$) and (ii) the correct orientation. Rate increases whenever collisions become *more frequent* and/or *more likely to succeed*.

Factor	Mechanism (collision theory)	Typical example
Concentration / pressure	More particles per unit volume ⇒ more *frequent* collisions (fraction successful unchanged)	Diluting the acid slows a reaction with a metal
Temperature	Particles move faster (more frequent collisions) *and* a far greater proportion have $E \geq E_a$ (more *successful* collisions)	A $10\,^{\circ}$C rise roughly doubles the rate of many reactions
Surface area / particle size	More particles exposed at an accessible surface ⇒ more frequent collisions	Powdered marble reacts faster than the same mass of chips
Catalyst	Opens an alternative pathway of lower E_a ⇒ a greater proportion of collisions are successful	Fe in the Haber process, V_2O_5 in the Contact process

VN **GIẢI THÍCH TIẾNG VIỆT**

Theo thuyết va chạm, các hạt chỉ phản ứng khi va chạm với nhau, có **đủ năng lượng** (tối thiểu bằng năng lượng hoạt hoá E_a) và **đúng hướng**. Tốc độ phản ứng tỉ lệ với tần số va chạm hiệu quả (thành công) trong một đơn vị thời gian. Bất kỳ thay đổi điều kiện nào làm tăng tần số va chạm hoặc tăng tỉ lệ va chạm thành công đều làm tăng tốc độ phản ứng.

6.1.1 Concentration and pressure

Increasing the **concentration** of a dissolved reactant, or the **pressure** of a gaseous reactant, packs more particles into the same volume. The particles are therefore closer together on average, so they collide **more frequently**. Since the average energy of the particles is unchanged, the *fraction* of collisions that are successful stays the same — the increase in rate comes entirely from the increase in collision frequency. Roughly speaking, doubling the concentration of a reactant roughly doubles the frequency of collisions involving that reactant.

VN **GIẢI THÍCH TIẾNG VIỆT**

Tăng **nồng độ** (chất tan) hoặc **áp suất** (chất khí) làm các hạt nằm gần nhau hơn trong cùng thể tích ⇒ va chạm xảy ra **thường xuyên hơn**. Tỉ lệ va chạm thành công không đổi (năng lượng trung bình của hạt không đổi) — tốc độ tăng hoàn toàn do tần số va chạm tăng.

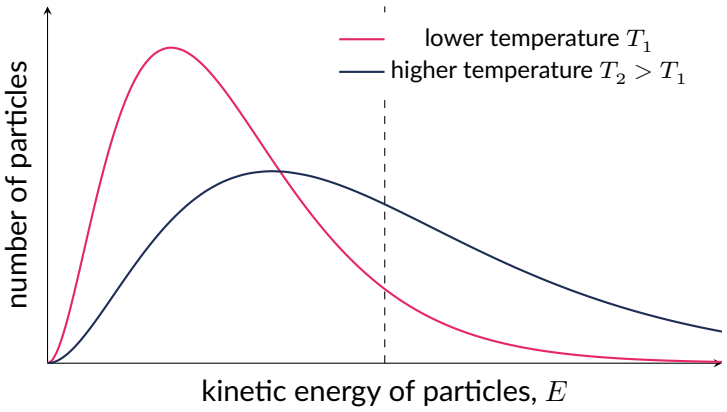
6.1.2 Temperature

Raising the **temperature** increases the rate of reaction far more strongly than a similarly-sized change in concentration. Two effects act together:

- Particles move faster (higher average kinetic energy), so they collide **more frequently**.
- Far more importantly, a much greater **proportion** of collisions now involve particles with combined energy $\geq E_a$, so a much greater proportion of collisions are **successful**.

As a rough working rule at this level, a rise of about $10\,^{\circ}$C can roughly double the rate of many reactions — driven almost entirely by the second effect (more successful collisions), not the first (more frequent collisions).

(Supplement) **The Maxwell–Boltzmann distribution.** At any fixed temperature, the particles of a gas (or of a solution) do not all share the same kinetic energy — their energies are spread over a continuous range, described by the Maxwell–Boltzmann distribution. Raising the temperature from a lower value T_1 to a higher value T_2: the peak of the curve becomes **lower** and shifts to the **right**, and the curve becomes **broader** — but the total area under the curve is unchanged (the total number of particles has not changed). Crucially, the area under the curve to the right of E_a (the particles energetic enough to react) increases sharply. This disproportionately large increase in the number of successful collisions per second is what makes rate so sensitive to temperature.



(Supplement) Maxwell–Boltzmann distribution of particle energies at two temperatures. At the higher temperature T_2, the curve is lower and broader (same total area = same number of particles), but the shaded area beyond E_a — particles able to react — is much larger.

VN **GIẢI THÍCH TIẾNG VIỆT**

(Supplement) Phân bố Maxwell–Boltzmann mô tả sự phân bố năng lượng động học của các hạt ở một nhiệt độ nhất định. Khi tăng nhiệt độ, đỉnh đường cong **thấp hơn** và **lệch phải**, đường cong **rộng hơn**, nhưng diện tích dưới đường cong (tổng số hạt) không đổi. Diện tích bên phải E_a (số hạt đủ năng lượng phản ứng) tăng mạnh — đây là lý do tốc độ phản ứng tăng rất nhanh khi tăng nhiệt độ, nhanh hơn nhiều so với chỉ do va chạm thường xuyên hơn.

6.1.3 Surface area and particle size

For a reaction involving a solid, only particles **at the exposed surface** of the solid can collide with the other reactant — particles buried inside the solid are unavailable until the outer layers have reacted away. Breaking a solid into smaller pieces (or using a powder instead of a lump) increases the **total surface area** for the same total mass of solid, exposing more particles to collision and so increasing the rate — *without* changing the total amount of product eventually formed, since the total mass of solid reacting is the same.

A **catalyst** also increases rate, by an entirely different mechanism (an alternative pathway of lower activation energy); catalysts are examined in depth in Section 6.3.

(!) **Lỗi thường gặp:** Surface area affects only how many particles are exposed at any instant — it does *not* change the total mass of solid that eventually reacts, so the total volume of gas (or mass of precipitate) produced by completion is the **same** whether the solid is a lump or a powder. A powdered solid reacts **faster**, reaching the same final volume **sooner** — it does not produce *more* product.

VN **GIẢI THÍCH TIẾNG VIỆT**

Với chất rắn, chỉ các hạt ở **bề mặt tiếp xúc** mới có thể va chạm với chất phản ứng còn lại. Nghiền nhỏ chất rắn (dùng bột thay vì cục lớn) làm tăng **tổng diện tích bề mặt** với cùng khối lượng ⇒ va chạm xảy ra thường xuyên hơn ⇒ tốc độ tăng — nhưng **tổng lượng sản phẩm** tạo thành khi phản ứng hoàn tất là **không đổi**.

6.2 Measuring rate experimentally

Because most reactions are too fast, too slow, or too gradual to time by eye, chemists measure some physical quantity that changes as the reaction proceeds and record it against time. Four methods are common at this level.

6.2.1 Volume of gas produced

When a reaction produces a gas — e.g. $CaCO_3 + 2HCl -> CaCl_2 + H_2O + CO_2$, or a reactive metal with an acid producing H_2 — the gas can be collected in a gas syringe, or by downward displacement of water in an inverted, graduated measuring cylinder, and its volume read at regular time intervals. A graph of total volume of gas collected against time is then plotted.

6.2.2 Loss in mass

If the gas produced is instead allowed to escape freely into the air, the reaction flask can be stood directly on a mass balance (with a loose plug of cotton wool in the neck to stop splashing, but let gas escape). As gas escapes, the total mass of flask and contents decreases steadily. A graph of **mass lost** against time has the same overall shape as the volume-of-gas graph: a steep initial fall, gradually levelling off to a constant final mass once the reaction is complete.

Ví dụ mẫu · Worked example — calculating rate from mass loss

In an experiment, excess dilute hydrochloric acid was added to 5.0 g of marble chips ($CaCO_3$) in a conical flask standing on a mass balance, and the mass of the flask and contents was recorded every 20 s:

time (s)	0	20	40	60	80
mass lost (g)	0	0.34	0.52	0.60	0.60

Calculate (a) the average rate of mass loss between 0 and 40 s, and (b) the average rate between 40 s and 80 s. Comment on the difference.

(a) rate $= \dfrac{0.52 - 0}{40 - 0} = \dfrac{0.52}{40} = 0.013$ g/s.

(b) rate $= \dfrac{0.60 - 0.52}{80 - 40} = \dfrac{0.08}{40} = 0.0020$ g/s.

The rate in the second interval is much lower than in the first, because the concentration of acid (and the amount of unreacted marble) has fallen; by 80 s the mass has stopped changing altogether, showing the reaction is complete (the acid or the marble — whichever is limiting — has been fully used up).

6.2.3 Time for a precipitate to obscure a mark

For a reaction that produces an insoluble precipitate — the classic example is sodium thiosulfate with dilute hydrochloric acid, $Na_2S_2O_3 + 2HCl -> 2NaCl + SO_2 + S + H_2O$, which produces a fine pale-yellow precipitate of sulfur — the reaction mixture is placed in a flask standing over a piece of paper marked with a cross. As the precipitate forms, the mixture becomes increasingly cloudy, and at some point the cross viewed from above can no longer be seen. The **time taken for the cross to**

disappear, t, is recorded. A faster reaction gives a *shorter* time, so the rate is taken to be proportional to $1/t$, not to t itself.

Ví dụ mẫu · Worked example — the disappearing-cross method and concentration

The sodium thiosulfate–hydrochloric acid reaction was repeated at two different thiosulfate concentrations, with everything else unchanged. The cross disappeared after 40 s using the original solution, and after 20 s using a solution of double the concentration. Compare the two rates.

$$\text{rate}_1 = \frac{1}{40} = 0.025\ \text{s}^{-1}, \qquad \text{rate}_2 = \frac{1}{20} = 0.050\ \text{s}^{-1}.$$

Doubling the concentration of thiosulfate ions doubled the rate of reaction ($\text{rate}_2 = 2 \times \text{rate}_1$) — consistent with collision theory, since doubling concentration doubles the frequency of collisions between reacting particles.

6.2.4 Colour change (colorimetry)

If a reactant or product is coloured, the reaction can be followed by monitoring how the intensity of colour changes with time — by eye against colour standards, or more precisely with a **colorimeter**, an instrument that measures how much light of a chosen colour is absorbed by the solution. For example, the fading of orange bromine water as it reacts with an alkene, or the iodine–propanone reaction, can be timed this way; a colorimeter produces an absorbance-against-time graph, which is proportional to a concentration-against-time graph.

6.2.5 Interpreting rate–time graphs

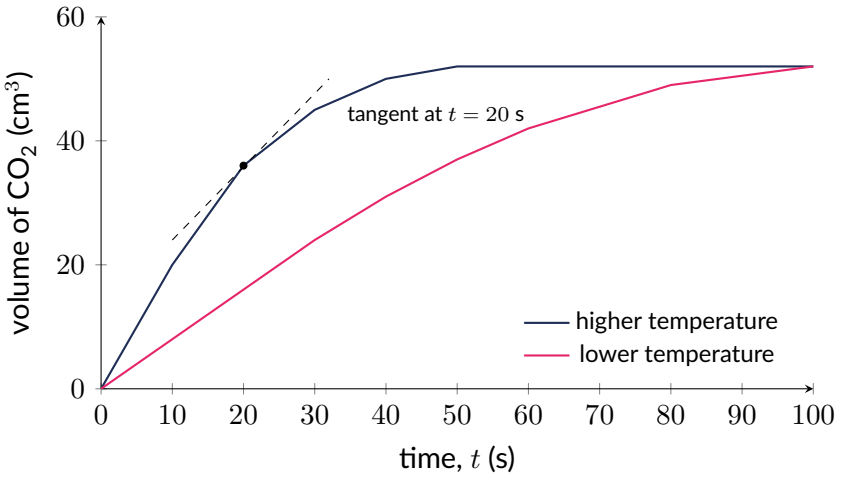
Whichever method is used, the resulting graph typically has the same overall shape: steepest at the very start (reactants are at their highest concentration, so collisions are most frequent), becoming progressively less steep as reactants are used up, and finally **horizontal** (zero gradient) once the reaction is complete or a reactant is fully used up — the quantity plotted then stays constant.

The **gradient of the tangent** to a rate–time graph at a given point gives the **instantaneous rate** at that moment:

$$\text{rate at time } t \;=\; \text{gradient of the tangent to the curve at } t.$$

The **average rate** over an interval, in contrast, is found from the straight line (chord) joining the two end points of that interval:

$$\text{average rate} \;=\; \frac{\text{change in quantity measured}}{\text{change in time}} \;=\; \frac{\Delta y}{\Delta t}.$$



Same reaction at two temperatures: the higher-temperature curve has a steeper initial gradient (faster rate) but reaches the same final volume (same amount of limiting reactant used up). The dashed line is the tangent drawn to find the instantaneous rate at $t = 20$ s (see the worked example below).

VN **GIẢI THÍCH TIẾNG VIỆT**

Đồ thị tốc độ luôn có dạng: dốc nhất lúc đầu, thoải dần khi chất phản ứng cạn kiệt, và **nằm ngang** khi phản ứng kết thúc. **Độ dốc của tiếp tuyến** tại một thời điểm cho **tốc độ tức thời** tại thời điểm đó; **độ dốc của đường nối hai điểm** cho **tốc độ trung bình** trong khoảng thời gian đó.

(!) Lỗi thường gặp: The units of rate depend entirely on what quantity is being measured, and must always be stated: cm^3/s (or $\text{cm}^3\,\text{min}^{-1}$) for a volume of gas, g/s for a mass loss, $\text{mol}\,\text{dm}^{-3}\,\text{s}^{-1}$ for a concentration change, and s^{-1} (i.e. using $1/t$) when timing a fixed observation such as a disappearing cross. Do not report a "$1/t$" rate with volume units, or vice versa.

Ví dụ mẫu · Worked example — rate from the gradient of a graph

Using the tangent drawn on the graph above at $t = 20$ s, which passes through the points $(10\text{ s},\ 24\text{ cm}^3)$ and $(32\text{ s},\ 50\text{ cm}^3)$, calculate the instantaneous rate of reaction at $t = 20$ s.

$$\text{rate} = \frac{\Delta y}{\Delta t} = \frac{50 - 24}{32 - 10} = \frac{26}{22} \approx 1.2\ \text{cm}^3/\text{s}.$$

Ví dụ mẫu · Worked example — average rate between two time points

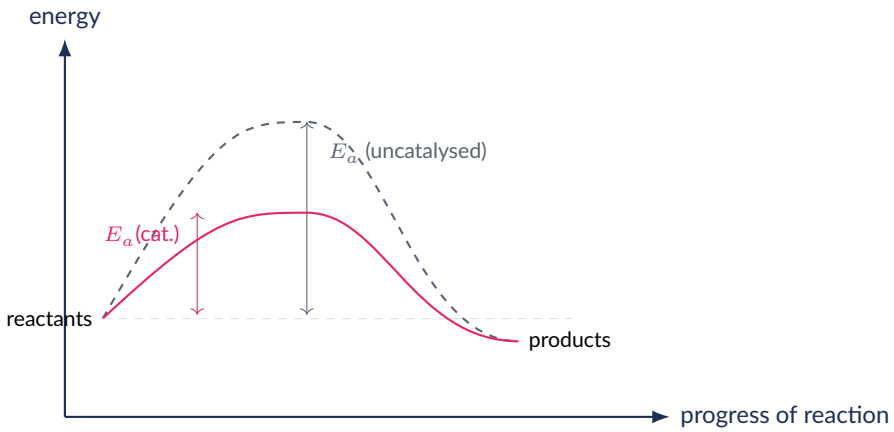
In an experiment, the volume of gas collected was 30 cm^3 at 20 s and 54 cm^3 at 60 s. Calculate the average rate of reaction between 20 s and 60 s.

$$\text{average rate} = \frac{54 - 30}{60 - 20} = \frac{24}{40} = 0.6\ \text{cm}^3/\text{s}.$$

Note this is an *average* over the interval — the instantaneous rate at $t = 20$ s (found from a tangent) would be noticeably higher, since the reaction is slowing down throughout this interval.

6.3 Catalysts

A **catalyst** is a substance that increases the rate of a chemical reaction without itself being permanently changed or used up — the same particles of catalyst can, in principle, be recovered unchanged at the end and reused. A catalyst achieves this by providing an **alternative reaction pathway** with a **lower activation energy** than the uncatalysed route. Because more collisions now have enough energy to follow this easier pathway, a much greater fraction of collisions are successful, so the rate increases — even though the temperature, concentrations, and everything else about the reactants and products are unchanged.



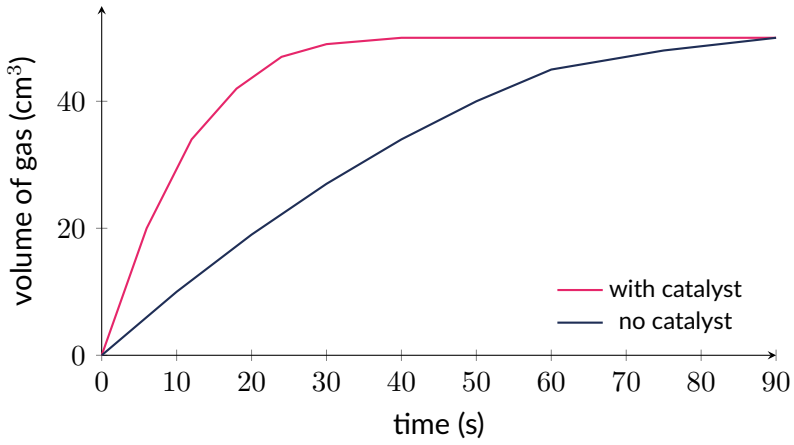
A catalyst opens an alternative pathway (pink) with lower activation energy than the uncatalysed pathway (grey, dashed). The energies of the reactants and products — and hence ΔH — are unchanged.

VN **GIẢI THÍCH TIẾNG VIỆT**

Chất xúc tác làm tăng tốc độ phản ứng bằng cách tạo ra một **con đường phản ứng khác** với **năng lượng hoạt hoá thấp hơn**, mà không bị tiêu hao và không làm thay đổi ΔH hay sản phẩm của phản ứng.

Khái niệm cốt lõi

A catalyst is typically **specific**: a catalyst that speeds up one reaction usually has no effect on a different reaction. Because it is regenerated at the end of the reaction, a catalyst is *not* written as a reactant or product in the balanced equation — it is conventionally written above (or below) the reaction arrow.



Adding a catalyst makes the reaction reach completion much sooner (steeper initial gradient), but the **final volume of gas is identical** — the same total amount of reactant is eventually converted either way. This is the graphical signature that a change has affected *rate* only, not the overall amount of product.

VN **GIẢI THÍCH TIẾNG VIỆT**

Đồ thị so sánh phản ứng có và không có xúc tác: đường có xúc tác dốc hơn (đạt hoàn tất nhanh hơn) nhưng **thể tích khí cuối cùng bằng nhau** — xúc tác chỉ làm tăng tốc độ, không làm tăng lượng sản phẩm.

6.3.1 Biological and industrial catalysts

Enzymes are biological catalysts — protein molecules that catalyse specific reactions inside living cells (e.g. amylase catalyses the breakdown of starch into simpler sugars). Enzymes work fastest within a narrow **optimum temperature** (often around 35–$40\,^{\circ}\text{C}$ in the human body) and a specific **optimum pH**; outside these ranges, the enzyme's delicate three-dimensional shape is disrupted — it is **denatured** — and it permanently loses its catalytic activity.

Industry relies heavily on catalysts to make large-scale processes economically viable. Two named catalysts appear repeatedly in this chapter:

- **Iron (Fe)** — catalyses the Haber process, $N_2 + 3H_2 \rightleftharpoons 2NH_3$ (Section 6.5).
- **Vanadium(V) oxide (V_2O_5)** — catalyses the Contact process, $2SO_2 + O_2 \rightleftharpoons 2SO_3$ (Section 6.5).

> **(!) Lỗi thường gặp:** A catalyst changes only the **rate** at which a reversible reaction reaches equilibrium — it never changes the **position** of equilibrium (Section 6.5). Confusing these two ideas is one of the most common errors at this level: "faster" is not the same as "more product."

6.4 Reversible reactions and dynamic equilibrium

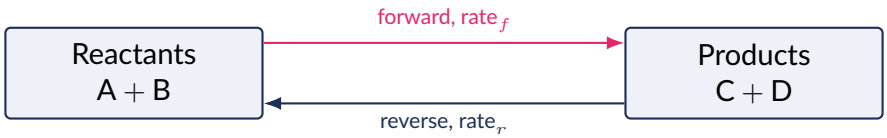
A **reversible reaction** can proceed in both directions, shown using the symbol $\rightleftharpoons$. When a reversible reaction takes place in a **closed system** — one from which no reactant or product can escape, and into which nothing new can enter — it eventually reaches **dynamic equilibrium**.

6.4.1 Closed systems and dynamic equilibrium

At dynamic equilibrium:

- Both the forward and the reverse reactions are still occurring — nothing has "stopped."
- They occur at exactly **equal rates**.
- As a result, the concentrations of every reactant and product remain **constant** over time (though these concentrations are not necessarily equal to one another).

Dynamic equilibrium can only be established in a *closed* system. In an open system, if a product — especially a gas — is free to escape, the reverse reaction cannot build up to any significant extent, and the reaction simply runs towards completion in the forward direction instead of settling into equilibrium.



at dynamic equilibrium: rate$_f$ = rate$_r$
(both reactions continue; concentrations stay constant)

Dynamic equilibrium in a closed system: forward and reverse reactions both continue, at equal rates (equal-length arrows), so macroscopic concentrations no longer change.

> **VN GIẢI THÍCH TIẾNG VIỆT**
> Phản ứng thuận nghịch (kí hiệu $\rightleftharpoons$) xảy ra trong **hệ kín** sẽ đạt **cân bằng động**: cả hai chiều phản ứng vẫn tiếp diễn, với **tốc độ bằng nhau**, nên nồng độ các chất không đổi theo thời gian (nhưng không nhất thiết bằng nhau). Nếu hệ không kín (chất khí thoát ra ngoài), cân bằng không thể thiết lập — phản ứng sẽ đi đến hoàn toàn theo một chiều.

6.4.2 The hydrated copper(II) sulfate test

$$CuSO_4 \cdot 5H_2O \rightleftharpoons CuSO_4 + 5H_2O$$

Blue hydrated copper(II) sulfate crystals lose their water of crystallisation on heating, leaving white anhydrous copper(II) sulfate powder (forward reaction, endothermic). Adding water back to the white powder regenerates the blue hydrated solid (reverse reaction, exothermic — the mixture becomes noticeably warm to the touch). Because the colour change is so distinctive, anhydrous copper(II) sulfate is used as a simple **chemical test for the presence of water**: any liquid that turns white anhydrous $CuSO_4$ blue contains water.

Chemists often describe an equilibrium mixture informally as "lying mostly to the right" (mostly products) or "lying mostly to the left" (mostly reactants). This is simply a shorthand for saying the equilibrium concentrations of products are much greater (or much smaller) than those of the reactants — it says nothing about whether the system has "finished reacting" (it has not: both reactions continue).

(!) Lỗi thường gặp: "Equilibrium" does not mean the reaction has stopped, and it does not mean the amounts of reactants and products are equal — it means both reactions are still occurring, at equal rates, so the (generally unequal) concentrations stay constant. Equilibrium can only be reached in a **closed** system; if any substance is free to escape, the reaction runs to completion instead.

Ví dụ mẫu · Worked example — catalyst and time to reach equilibrium

A reversible reaction is allowed to reach equilibrium twice: once with no catalyst, and once with a suitable catalyst present. Compare (a) the time taken to reach equilibrium and (b) the equilibrium yield in the two runs.

(a) A catalyst lowers the activation energy of *both* the forward and the reverse reaction by the same amount, so both rates increase by the same factor. Equilibrium (where $\text{rate}_f = \text{rate}_r$) is therefore reached **sooner** with the catalyst present.
(b) Because forward and reverse rates are sped up *equally* — neither direction is favoured over the other — the concentrations present once equilibrium is reached (the yield) are **unchanged**. The catalyst changes only how quickly equilibrium is reached, never its position.

6.5 Le Chatelier's principle and equilibrium position

(Supplement) **Le Chatelier's principle** states: if a system at dynamic equilibrium is subjected to a change in concentration, temperature, or pressure, the position of equilibrium shifts so as to **oppose (partially cancel out)** the change, until a new equilibrium is established.

Khái niệm cốt lõi — ba quy tắc của Le Chatelier

(Supplement)

- **Concentration**: increasing the concentration of a substance on one side shifts equilibrium *away* from that side (to use some of it up); decreasing it shifts equilibrium *towards* that side (to replace some of it).
- **Temperature**: increasing temperature shifts equilibrium in the **endothermic** direction (to absorb the extra heat); decreasing temperature shifts it in the **exothermic** direction (to release heat).
- **Pressure** (gaseous systems only): increasing pressure shifts equilibrium towards the side

with **fewer** gas molecules (to reduce the pressure); decreasing pressure shifts it towards the side with **more** gas molecules. If both sides have equal numbers of gas molecules, pressure has no effect on the position of equilibrium.

A **catalyst** affects none of these — it changes only the rate of reaching equilibrium (Section 6.3–6.4).

VN **GIẢI THÍCH TIẾNG VIỆT**

(Supplement) Nguyên lý Le Chatelier: khi một hệ đang ở cân bằng bị thay đổi nồng độ, nhiệt độ hoặc áp suất, cân bằng sẽ **dịch chuyển để chống lại** sự thay đổi đó. Tăng áp suất → dịch về phía **ít phân tử khí hơn**; tăng nhiệt độ → dịch về phía **thu nhiệt**; chất xúc tác **không** làm dịch chuyển cân bằng, chỉ giúp đạt cân bằng nhanh hơn.

6.5.1 Concentration changes, and when pressure has no effect

(Supplement) Before turning to the two large industrial case studies, it is worth applying the concentration and pressure rules to a simpler, generic equilibrium.

Ví dụ mẫu · Worked example — concentration change and a pressure-invariant equilibrium

(Supplement) For the equilibrium $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$: (a) predict the effect of increasing the concentration of H_2; (b) predict the effect of increasing the total pressure.

(a) Adding more H_2 increases the concentration of a reactant. By Le Chatelier's principle, equilibrium shifts *away* from the side that has increased — i.e. to the **right** — using up some of the added H_2 (together with I_2) to form more HI, partially (not completely) opposing the increase.

(b) Count gas molecules: $1 + 1 = 2$ mol on the left, 2 mol on the right — **equal** numbers of gas molecules on both sides. Since neither direction reduces the total number of gas molecules more than the other, changing the pressure has **no effect** on the position of this equilibrium (although it does still affect how quickly equilibrium is reached).

(!) Lỗi thường gặp: (Supplement) Do not assume every gaseous equilibrium is pushed by pressure. Always compare the *number of moles of gas* on each side of the equation first: if the two sides are equal (as in $H_2 + I_2 \rightleftharpoons 2HI$), pressure changes do not shift the equilibrium position at all.

(Supplement) Industrially, equilibrium yield can also be increased by continuously **removing a product** as it forms — this lowers the product concentration below its equilibrium value, so by Le Chatelier's principle the equilibrium continually shifts right to replace it. In the Haber process, ammonia is liquefied and removed as the gas mixture cools, while unreacted N_2 and H_2 are recycled; in the Contact process, SO_3 is absorbed into concentrated sulfuric acid (forming oleum, which is then diluted) as it forms. Both strategies push the equilibrium continually towards more product, increasing the overall conversion achieved across the whole plant even though the yield reached in a single pass through the reactor is modest.

VN **GIẢI THÍCH TIẾNG VIỆT**

(Supplement) Nếu số mol khí hai bên phương trình **bằng nhau** (như $H_2 + I_2 \rightleftharpoons 2HI$), thay đổi áp suất **không** làm dịch chuyển cân bằng. Trong công nghiệp, việc **liên tục lấy sản phẩm ra** (hoá lỏng NH_3, hấp thụ SO_3 vào H_2SO_4 đặc) làm giảm nồng độ sản phẩm, khiến cân bằng liên tục dịch chuyển theo chiều thuận để tạo thêm sản phẩm, tăng hiệu suất chuyển hoá tổng thể của cả nhà máy.

6.5.2 Case study: the Haber process

(Supplement) The Haber process manufactures ammonia from nitrogen and hydrogen:

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -93 \text{ kJ/mol (forward reaction exothermic).}$$

Ví dụ mẫu · Worked example — Le Chatelier applied to the Haber process

(Supplement) For the equilibrium $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$, $\Delta H = -93$ kJ/mol, predict the effect on the equilibrium yield of ammonia of (a) increasing the pressure and (b) increasing the temperature.

(a) **Pressure.** Count gas molecules: $1 + 3 = 4$ mol of gas on the left, 2 mol of gas on the right. Increasing pressure shifts equilibrium towards the side with *fewer* gas molecules — the right-hand side — so **more** NH_3 is formed at equilibrium; the yield increases.

(b) **Temperature.** The forward reaction is exothermic, so the reverse reaction is endothermic. Increasing temperature always favours the endothermic direction — here, the *reverse* reaction — so equilibrium shifts **left**: **less** NH_3 is formed at equilibrium; the yield decreases (even though the *rate* of reaching equilibrium increases).

6.5.3 Case study: the Contact process

(Supplement) The Contact process manufactures sulfur trioxide (used to make sulfuric acid) from sulfur dioxide and oxygen:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H \approx -196 \text{ kJ/mol (forward reaction exothermic).}$$

Ví dụ mẫu · Worked example — Le Chatelier applied to the Contact process

(Supplement) For the equilibrium $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$, predict and explain the effect on the equilibrium yield of SO_3 of (a) increasing the pressure and (b) increasing the temperature.

(a) **Pressure.** Gas molecules: $2 + 1 = 3$ mol on the left, 2 mol on the right. Increasing pressure shifts equilibrium towards the side with fewer gas molecules — the right — so **more** SO_3 forms; the yield increases.

(b) **Temperature.** The forward reaction is exothermic, so increasing temperature shifts equilibrium towards the endothermic (reverse) direction: **less** SO_3 forms at equilibrium; the yield decreases, although the reaction reaches equilibrium faster.

6.5.4 Rate versus yield: why industry chooses a compromise

(Supplement) Le Chatelier's principle tells us how to get the highest possible *yield* — but a high yield reached only after days or weeks is commercially useless. Real industrial plants therefore choose **compromise conditions** that balance an acceptable *yield* against an acceptable *rate*.

Haber process: a very high pressure (very much above atmospheric) would give the highest NH_3 yield, but the equipment required to withstand such pressure is extremely expensive and hazardous to run. A very low temperature would also give a higher yield (favouring the exothermic forward reaction), but the rate would then be far too slow to be economical. Industrially, a compromise of about $450\,^{\circ}$C and about 200 atmospheres is used, together with an **iron catalyst** to increase the rate at this moderate temperature without needing to raise the temperature (and so sacrifice yield) any further. Because the single-pass yield is still modest (roughly 15%), unreacted N_2 and H_2 are separated from the liquefied ammonia and recycled back through the reactor.

Contact process: because sulfur dioxide and oxygen already react to give a very high yield of SO_3 (about 98%) at close to atmospheric pressure once the V_2O_5 catalyst and a moderate temperature are used, the small additional yield that high pressure would provide is not worth the substantial extra cost, and corrosion/safety risk, of high-pressure equipment for handling SO_2/SO_3. A compromise temperature of about $450\,^\circ$C is used: low enough to keep the equilibrium yield high, but high enough — helped by the V_2O_5 catalyst — for the reaction to reach equilibrium in a reasonable time.

VN **GIẢI THÍCH TIẾNG VIỆT**

(Supplement) Trong công nghiệp, điều kiện vận hành luôn là sự **thoả hiệp giữa tốc độ và hiệu suất**: điều kiện cho hiệu suất cao nhất (áp suất rất cao, nhiệt độ rất thấp) thường khiến tốc độ quá chậm hoặc chi phí thiết bị quá lớn. Quá trình Haber dùng khoảng $450\,^\circ$C, 200 atm với xúc tác Fe; quá trình Contact dùng khoảng $450\,^\circ$C, áp suất gần khí quyển với xúc tác V_2O_5 — vì hiệu suất đã rất cao ở áp suất thường nên không cần tăng áp suất.

Haber process: $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$, $\Delta H = -93$ kJ/mol

Change	Shift	Reasoning
Increase pressure	Right (→ more NH_3)	Shifts towards the side with fewer gas molecules (2 mol vs 4 mol) to oppose the increase in pressure.
Decrease pressure	Left (→ more N_2, H_2)	Shifts towards the side with more gas molecules to oppose the decrease in pressure.
Increase temperature	Left (→ less NH_3)	Forward reaction is exothermic; system shifts in the endothermic (reverse) direction to absorb the extra heat.
Decrease temperature	Right (→ more NH_3)	Shifts in the exothermic (forward) direction to release heat and oppose the decrease.
Add Fe catalyst	No change	Speeds up forward and reverse rates equally; equilibrium reached faster, yield unchanged.

Contact process: $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$, $\Delta H \approx -196$ kJ/mol

Change	Shift	Reasoning
Increase pressure	Right (→ more SO_3)	Shifts towards the side with fewer gas molecules (2 mol vs 3 mol).
Increase temperature	Left (→ more SO_2, O_2)	Forward reaction is exothermic; increasing T favours the endothermic (reverse) direction.
Decrease temperature	Right (→ more SO_3)	Favours the exothermic (forward) direction, but the rate becomes very slow.
Add V_2O_5 catalyst	No change	Increases rate of both directions equally; allows a lower, more economical operating temperature.

(!) Lỗi thường gặp: **(Supplement)** Two direction errors are common here. First, "fewer gas molecules" always refers to the *number of moles of gaseous species in the balanced equation*, never to physical volume or mass — always count moles of gas on each side first. Second, for temperature, always identify *which direction is exothermic* before reasoning: increasing temperature always favours the endothermic direction, whether that happens to be the forward or the reverse reaction — never simply assume "hotter always means more product."

6.6 Redox reactions

Two equivalent definitions of oxidation and reduction are used at this level.

In terms of electron transfer (the more fundamental definition): **Oxidation** is the **loss** of electrons; **Reduction** is the **gain** of electrons — remembered by the mnemonic **OIL RIG** (*Oxidation Is Loss, Reduction Is Gain*).

In terms of oxygen/hydrogen transfer (useful when no simple ions are involved): **Oxidation** is the gain of oxygen, or the loss of hydrogen; **Reduction** is the loss of oxygen, or the gain of hydrogen.

Both definitions describe the same underlying chemical change and always agree with one another for a given reaction.

VN **GIẢI THÍCH TIẾNG VIỆT**

Oxi hoá = mất electron (hoặc thêm oxygen/mất hydrogen); khử = nhận electron (hoặc mất oxygen/thêm hydrogen). Ghi nhớ bằng **OIL RIG**: *Oxidation Is Loss, Reduction Is Gain*. Hai cách định nghĩa (theo electron và theo oxygen/hydrogen) luôn cho cùng một kết quả.

Ví dụ mẫu · Worked example — the oxygen/hydrogen definition

When hydrogen gas is passed over heated black copper(II) oxide, $CuO + H_2 -> Cu + H_2O$, the black solid turns pink-brown (copper metal) and water is formed. Identify, using the oxygen/hydrogen definition, which species is oxidised and which is reduced.

CuO **loses** oxygen to become Cu $\Rightarrow$ CuO is **reduced**.
H_2 **gains** oxygen to become H_2O $\Rightarrow$ H_2 is **oxidised**.

This agrees exactly with the electron-transfer picture: copper goes from Cu^{2+} (oxidation state $+2$, in CuO) to Cu (oxidation state 0) — a decrease, confirming reduction — while hydrogen goes from 0 (in H_2) to $+1$ (in H_2O) — an increase, confirming oxidation. H_2 is the reducing agent; CuO is the oxidising agent.

6.6.1 Oxidising and reducing agents

The species that is **reduced** (it gains electrons) is called the **oxidising agent** — it removes electrons from, i.e. *oxidises*, something else. The species that is **oxidised** (it loses electrons) is called the **reducing agent** — it supplies electrons to, i.e. *reduces*, something else.

A useful check: the **oxidising agent** always ends up *reduced*, and the **reducing agent** always ends up *oxidised* — never the other way round.

6.6.2 Half-equations for displacement reactions

Ví dụ mẫu · Worked example — half-equations, Zn + $CuSO_4$

For the displacement reaction $Zn + CuSO_4 -> ZnSO_4 + Cu$, write the two half-equations and identify the oxidising agent and the reducing agent.

Oxidation (electron loss): $Zn -> Zn^{2+} + 2e^-$.
Reduction (electron gain): $Cu^{2+} + 2e^- -> Cu$.

Zn is the **reducing agent** (it is oxidised); Cu^{2+} (in $CuSO_4$) is the **oxidising agent** (it is reduced).

Ví dụ mẫu · Worked example — halogen displacement

Chlorine gas is bubbled through potassium bromide solution: $Cl_2 + 2KBr -> 2KCl + Br_2$. Write the half-equations and identify the oxidising and reducing agents.

Oxidation (electron loss): $2Br^- -> Br_2 + 2e^-$.
Reduction (electron gain): $Cl_2 + 2e^- -> 2Cl^-$.

Cl_2 is the **oxidising agent** (it is reduced, gaining electrons); KBr (its Br^- ion) is the **reducing agent** (it is oxidised). This is why chlorine can displace bromine from a bromide, but bromine cannot displace chlorine from a chloride — chlorine is the stronger oxidising agent.

6.7 Oxidation states

(Supplement) An **oxidation state** (oxidation number) is a bookkeeping number assigned to each atom in a substance, based on a set of agreed rules. Tracking how oxidation states change lets us identify oxidation and reduction even when no simple ions are involved and electron transfer is not obvious by inspection.

Khái niệm cốt lõi — quy tắc xác định số oxi hoá

(Supplement)

1. Any uncombined element (e.g. Fe, O_2, Cl_2) has oxidation state 0.
2. A simple (monatomic) ion has oxidation state equal to its charge, e.g. Mg^{2+} is $+2$, Cl^- is -1.
3. Oxygen is -2 in almost all compounds (exception: peroxides such as H_2O_2, where it is -1).
4. Hydrogen is $+1$ in almost all compounds (exception: metal hydrides such as NaH, where it is -1).
5. Group I metals are always $+1$, and Group II metals always $+2$, in their compounds.
6. The oxidation states of all atoms in a **neutral compound** sum to 0; in an **ion**, they sum to the charge on the ion.

VN **GIẢI THÍCH TIẾNG VIỆT**

(Supplement) Số oxi hoá là con số quy ước gán cho mỗi nguyên tử theo các quy tắc: nguyên tố đơn chất $= 0$; ion đơn nguyên tử $=$ điện tích ion; oxygen thường -2; hydrogen thường $+1$; tổng số oxi hoá trong hợp chất trung hoà $= 0$, trong ion $=$ điện tích ion.

Ví dụ mẫu · Worked example — Cr in the dichromate ion

(Supplement) Determine the oxidation state of chromium in the dichromate ion, $Cr_2O_7^{2-}$.
Let the oxidation state of Cr be x. Oxygen is -2; the ion's overall charge is -2:

$$2x + 7(-2) = -2 \;\Rightarrow\; 2x - 14 = -2 \;\Rightarrow\; 2x = 12 \;\Rightarrow\; x = +6.$$

Chromium is in the $+6$ oxidation state.

Ví dụ mẫu · Worked example — Mn in the manganate(VII) ion

(Supplement) Determine the oxidation state of manganese in the manganate(VII) ion, MnO_4^-.
Let the oxidation state of Mn be x. Oxygen is -2; the ion's overall charge is -1:

$$x + 4(-2) = -1 \;\Rightarrow\; x - 8 = -1 \;\Rightarrow\; x = +7.$$

Manganese is in the $+7$ oxidation state.

Ví dụ mẫu · Worked example — sulfur in H_2SO_4 and SO_2

(Supplement) Compare the oxidation state of sulfur in sulfuric acid, H_2SO_4, and in sulfur dioxide, SO_2.
H_2SO_4 (neutral compound): $2(+1) + x + 4(-2) = 0 \;\Rightarrow\; 2 + x - 8 = 0 \;\Rightarrow\; x = +6$.
SO_2 (neutral compound): $x + 2(-2) = 0 \;\Rightarrow\; x = +4$.

Sulfur is $+6$ in H_2SO_4 but only $+4$ in SO_2. In the Contact process, SO_2 is *oxidised* to SO_3 (sulfur $+4 \rightarrow +6$) before being converted to H_2SO_4 (still $+6$) — the final acid-forming step is not itself a redox change.

Ví dụ mẫu · Worked example — the peroxide and metal-hydride exceptions

(Supplement) Determine the oxidation state of oxygen in hydrogen peroxide, H_2O_2, and of hydrogen in sodium hydride, NaH.

H_2O_2: here oxygen is *not* -2 (rule 3 exception — a peroxide). Since H $= +1$: $2(+1) + 2x = 0 \Rightarrow x = -1$. Oxygen is -1 in a peroxide.
NaH: here hydrogen is *not* $+1$ (rule 4 exception — a metal hydride). Since Na is a Group I metal, Na $= +1$: $(+1) + x = 0 \Rightarrow x = -1$. Hydrogen is -1 in a metal hydride.

These two exceptions are worth memorising, since applying the "normal" values of -2 for O or $+1$ for H would give the wrong answer for every other atom in the formula.

6.7.1 Using oxidation-state change to track redox

(Supplement) If a species' oxidation state **increases**, it has been **oxidised**; if it **decreases**, it has been **reduced**. This works even for reactions between covalent, uncharged species where no obvious ions or electron transfer are visible.

Ví dụ mẫu · Worked example — Fe_2O_3 + CO without obvious electron transfer

(Supplement) In the reaction $Fe_2O_3 + 3CO -> 2Fe + 3CO_2$, use oxidation states to identify which species is oxidised and which is reduced, and name the oxidising and reducing agents.

Fe: $+3$ in $Fe_2O_3 \rightarrow 0$ in Fe — oxidation state *decreases* $\Rightarrow$ Fe is **reduced**.
C: $+2$ in CO $\rightarrow +4$ in CO_2 — oxidation state *increases* $\Rightarrow$ C is **oxidised**.

CO is the **reducing agent** (it is oxidised, and it removes oxygen from the iron oxide); Fe_2O_3 is the **oxidising agent** (it is reduced). Although no simple ions are present, the oxidation-state method still identifies the redox changes clearly.

Ví dụ mẫu · Worked example — nitrogen oxidation states across several species

(Supplement) Determine the oxidation state of nitrogen in NH_3, N_2O, NO, NO_2, and HNO_3.

NH_3: $x + 3(+1) = 0 \Rightarrow x = -3$.
N_2O: $2x + (-2) = 0 \Rightarrow x = +1$.
NO: $x + (-2) = 0 \Rightarrow x = +2$.
NO_2: $x + 2(-2) = 0 \Rightarrow x = +4$.
HNO_3: $(+1) + x + 3(-2) = 0 \Rightarrow x = +5$.

Nitrogen can take many different oxidation states, from -3 (NH_3) up to $+5$ (HNO_3) — reflecting the wide variety of nitrogen compounds and the many redox reactions nitrogen can undergo.

Ví dụ mẫu · Worked example — identifying agents in a new redox equation

(Supplement) In the reaction $2Mg + CO_2 -> 2MgO + C$ (burning magnesium continues in an atmosphere of carbon dioxide), identify the species that is oxidised, the species that is reduced, and the oxidising and reducing agents.

Mg: $0 \to +2$ in MgO — oxidation state *increases* $\Rightarrow$ Mg is **oxidised**; Mg is the **reducing agent**.
C: $+4$ in $CO_2 \to 0$ in C — oxidation state *decreases* $\Rightarrow$ C is **reduced**; CO_2 is the **oxidising agent**.
This explains why a CO_2 fire extinguisher must never be used on a burning magnesium fire — magnesium is reactive enough to remove oxygen from CO_2 itself and keeps burning.

Key relationships from this chapter.

$$\text{rate} \propto (\text{collision frequency}) \times (\text{fraction of collisions successful}).$$

$$\text{average rate} = \frac{\Delta y}{\Delta t}, \qquad \text{rate at } t = \text{gradient of the tangent at } t.$$

Dynamic equilibrium: $\text{rate}_{\text{forward}} = \text{rate}_{\text{reverse}}$ in a closed system. Le Chatelier: a system opposes any imposed change in concentration, temperature, or pressure ((Supplement)). OIL RIG: oxidation = electron loss; reduction = electron gain. Oxidation states: element $= 0$; simple ion $=$ its charge; sum in a neutral species $= 0$; sum in an ion $=$ its charge ((Supplement)).

VN **GIẢI THÍCH TIẾNG VIỆT**
Tóm tắt: tốc độ phản ứng phụ thuộc tần số va chạm và tỉ lệ va chạm thành công; cân bằng động có tốc độ thuận = tốc độ nghịch trong hệ kín; nguyên lý Le Chatelier mô tả cách cân bằng phản ứng lại một thay đổi áp đặt; OIL RIG cho oxi hoá–khử theo electron; số oxi hoá dùng để theo dõi oxi hoá–khử khi không có electron chuyển rõ ràng.

6.8 Practice

Bài tập luyện tập

Which change would *decrease* the rate of a reaction between magnesium ribbon and dilute hydrochloric acid?

(A) Using magnesium powder instead of ribbon
(B) Increasing the temperature
(C) Using more dilute acid
(D) Adding a suitable catalyst

Lời giải chi tiết

More dilute acid means a lower concentration of H^+ ions, so collisions between H^+ and Mg are less frequent and the rate *decreases*. **(C)**.

Bài tập luyện tập

Powdered calcium carbonate is used instead of the same mass of large marble chips, reacting with excess dilute hydrochloric acid. Which statement is correct?

(A) The reaction is faster and produces more gas overall
(B) The reaction is faster but the same total volume of gas is produced
(C) The reaction is slower but produces more gas overall
(D) There is no change in rate or in the volume of gas produced

Lời giải chi tiết

Powder has much greater surface area than the same mass of chips, so collisions are more frequent and the reaction is faster; but the same total mass of $CaCO_3$ reacts either way, so the same total volume of CO_2 is eventually produced. **(B)**.

Bài tập luyện tập

Explain, in terms of collision theory, why increasing the concentration of hydrochloric acid increases the rate of its reaction with magnesium ribbon.

Lời giải chi tiết

A more concentrated acid has more H^+ ions per unit volume, so the ions are closer together on average and collide with the magnesium surface *more frequently*. The fraction of collisions that are successful is unaffected (particle energies are unchanged), so the increase in rate comes entirely from the increase in collision frequency.

Bài tập luyện tập

(Supplement) Sketch and describe how the Maxwell–Boltzmann distribution curve for a gas changes when the temperature is raised from T_1 to a higher temperature T_2, and use it to explain why the rate of reaction increases sharply with temperature.

Lời giải chi tiết

(Supplement) At T_2 the peak of the curve is lower and shifted to the right, and the curve is broader — the total area under the curve (total number of particles) is unchanged. The area under the curve beyond E_a (particles with enough energy to react) is much larger at T_2, so the proportion of successful collisions increases sharply, producing a much higher rate than the modest increase in collision frequency alone would give.

Bài tập luyện tập

Which method would be most suitable for following the rate of the reaction between sodium thiosulfate solution and dilute hydrochloric acid, which produces a fine yellow precipitate of sulfur?

(A) Measuring the volume of gas produced with a gas syringe

(B) Measuring the loss in mass of the flask and contents

(C) Timing how long it takes for a cross viewed through the mixture to disappear

(D) Measuring the temperature change of the mixture

Lời giải chi tiết

The precipitate of sulfur makes the mixture increasingly cloudy; timing how long a mark viewed through the flask takes to disappear (the "disappearing cross" method) is the standard way to follow this particular reaction. **(C)**.

Bài tập luyện tập

In an experiment measuring the volume of hydrogen gas produced when excess magnesium ribbon reacts with dilute hydrochloric acid, the volume collected was 18 cm^3 at 15 s and 42 cm^3 at 45 s. Calculate the average rate of reaction between 15 s and 45 s.

Lời giải chi tiết

$$\text{rate} = \frac{42 - 18}{45 - 15} = \frac{24}{30} = 0.8 \text{ cm}^3/\text{s}.$$

Bài tập luyện tập

A tangent drawn to a volume–time graph at $t = 10$ s passes through the points $(5 \text{ s}, 12 \text{ cm}^3)$ and $(18 \text{ s}, 42 \text{ cm}^3)$. Calculate the rate of reaction at $t = 10$ s.

Lời giải chi tiết

$$\text{rate} = \frac{42 - 12}{18 - 5} = \frac{30}{13} \approx 2.3 \text{ cm}^3/\text{s}.$$

Bài tập luyện tập

On a graph of volume of gas produced against time, for a reaction that goes to completion, the curve eventually becomes horizontal because:

(A) The gas produced escapes from the container

(B) One of the reactants has been completely used up, so no more gas can form

(C) The temperature has fallen back to room temperature

(D) The catalyst has stopped working

Lời giải chi tiết

Once a reactant is fully consumed, no further reaction (and no further gas) can be produced, so the total volume stays constant — a horizontal line (zero gradient = zero rate). **(B)**.

Bài tập luyện tập

A catalyst increases the rate of a reaction because it:

(A) Increases the average kinetic energy of the particles

(B) Increases the concentration of the reactants

(C) Provides an alternative reaction pathway with a lower activation energy

(D) Increases the total surface area of the reactants

Lời giải chi tiết

A catalyst opens up an alternative pathway with lower E_a, so a greater fraction of collisions have enough energy to react. **(C)**.

Bài tập luyện tập

Explain why only a small mass of catalyst is normally needed to speed up a large-scale industrial reaction, and why the catalyst does not appear in the balanced chemical equation.

Lời giải chi tiết

A catalyst is not consumed by the overall reaction — it takes part in intermediate steps but is regenerated unchanged at the end, so the same particles of catalyst can act again and again. Because it undergoes no net chemical change, it is not written as a reactant or product; it may instead be shown above the reaction arrow.

Bài tập luyện tập

Above its optimum temperature, an enzyme's rate of catalysis falls sharply because the enzyme:

(A) Evaporates from the reaction mixture

(B) Is used up more quickly at higher temperature

(C) Is denatured, losing the shape of its active site

(D) Reacts chemically with the substrate

Lời giải chi tiết

Excess heat disrupts the enzyme's three-dimensional structure, changing the shape of its active site so the substrate no longer fits — the enzyme is denatured and loses its activity, usually permanently. **(C)**.

Bài tập luyện tập

Which statement about a reversible reaction at dynamic equilibrium in a closed system is correct?

(A) The forward and reverse reactions have both stopped

(B) The forward reaction has stopped, but the reverse reaction continues

(C) The forward and reverse reactions continue, at equal rates

(D) The concentrations of reactants and products are always equal to each other

Lời giải chi tiết

Dynamic equilibrium means both reactions keep occurring, at equal rates, so concentrations stay constant (not necessarily equal to each other). **(C)**.

Bài tập luyện tập

White anhydrous copper(II) sulfate powder is added to an unknown colourless liquid and turns blue. What does this indicate, and is the change chemical or physical?

Lời giải chi tiết

The colour change indicates the liquid contains water: $CuSO_4 + 5H_2O -> CuSO_4 \cdot 5H_2O$ (white → blue). This is a **chemical** change — new bonds form as water of crystallisation is incorporated into the crystal lattice — although it is readily **reversed** by heating, which is why

the parent reaction is described as reversible.

Bài tập luyện tập

A reversible reaction is carried out in an open flask, and one of the products is a gas that escapes freely into the air. Which statement is correct?

(A) Dynamic equilibrium is reached more quickly than in a closed flask

(B) Dynamic equilibrium cannot be established; the reaction runs towards completion

(C) The reverse reaction rate increases without limit

(D) No reaction occurs at all

Lời giải chi tiết

With a product escaping, the reverse reaction cannot build up, so equilibrium cannot be reached — the forward reaction simply continues until a reactant runs out. **(B)**.

Bài tập luyện tập

(Supplement) For the equilibrium $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ ($\Delta H = -93$ kJ/mol), which single change would *increase* the equilibrium yield of ammonia?

(A) Increasing the temperature

(B) Decreasing the pressure

(C) Adding an iron catalyst

(D) Decreasing the temperature

Lời giải chi tiết

(Supplement) The forward reaction is exothermic, so *decreasing* temperature shifts equilibrium towards the exothermic (forward) direction, increasing the NH_3 yield (though more slowly). **(D)**.

Bài tập luyện tập

(Supplement) Explain, using the balanced equation, why increasing the pressure on the Haber process equilibrium $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ increases the equilibrium yield of ammonia.

Lời giải chi tiết

(Supplement) There are 4 mol of gas on the reactant side (1 N_2 + 3 H_2) but only 2 mol of gas on the product side (2 NH_3). By Le Chatelier's principle, increasing pressure shifts equilibrium towards the side with fewer gas molecules — i.e. towards the forward reaction — to oppose the increase in pressure, so the equilibrium yield of NH_3 increases.

Bài tập luyện tập

A catalyst is added to a reversible reaction already at equilibrium. What effect does this have on the position of equilibrium and on the time taken to reach it?

(A) Shifts equilibrium right; equilibrium reached faster

(B) No change in position; equilibrium reached faster

(C) Shifts equilibrium left; equilibrium reached slower

(D) No change in position; equilibrium reached slower

Lời giải chi tiết

A catalyst speeds up the forward and reverse reactions equally, so equilibrium is reached **faster**, but its **position is unchanged**. **(B)**.

Bài tập luyện tập

(Supplement) For the Contact process equilibrium $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ (exothermic forward reaction), predict and explain the effect of (a) increasing the pressure and (b) increasing the temperature on the equilibrium yield of sulfur trioxide.

Lời giải chi tiết

(Supplement) (a) 3 mol gas (2 SO_2 + 1 O_2) $\rightarrow$ 2 mol gas (2 SO_3); increasing pressure shifts equilibrium towards the side with fewer gas molecules (the right), increasing the SO_3 yield.
(b) The forward reaction is exothermic, so increasing temperature shifts equilibrium towards the endothermic (reverse) direction (the left), decreasing the SO_3 yield — though the reaction reaches equilibrium faster.

Bài tập luyện tập

(Supplement) The Contact process is industrially operated at only slightly above atmospheric pressure, even though a higher pressure would increase the equilibrium yield of SO_3. Suggest why.

Lời giải chi tiết

(Supplement) At the operating temperature (about $450\,^\circ$C) with the V_2O_5 catalyst, the equilibrium yield of SO_3 is already very high (about 98%) close to atmospheric pressure. The small additional yield gained from using much higher pressure would not justify the large extra cost of building and safely operating high-pressure equipment (and the corrosion risk of SO_2/SO_3 at high pressure), so an ordinary pressure is used instead.

Bài tập luyện tập

(Supplement) In the Haber process, a moderately high temperature of about $450\,^\circ$C is used instead of a much lower temperature, even though a lower temperature would give a higher equilibrium yield of ammonia. Why?

(A) The iron catalyst does not function below $450\,^\circ$C

(B) At a much lower temperature the rate of reaction would be too slow to be economical

(C) Nitrogen does not react with hydrogen below $450\,^\circ$C

(D) A lower temperature would shift the equilibrium to the left

Lời giải chi tiết

(Supplement) A lower temperature would indeed increase the equilibrium yield (forward reaction is exothermic), but the rate of reaching that equilibrium would be commercially too slow; $450\,^\circ$C is a compromise between an acceptable yield and an acceptable rate. **(B)**.

Bài tập luyện tập

In the reaction $2Mg + O_2 -> 2MgO$, which statement is correct?

(A) Mg is reduced; it is the oxidising agent
(B) Mg is oxidised; it is the reducing agent
(C) Mg is oxidised; it is the oxidising agent
(D) O_2 is oxidised; it is the reducing agent

Lời giải chi tiết

Mg loses electrons ($0 \to +2$), so it is oxidised; a species that is oxidised is the **reducing agent**. **(B)**.

Bài tập luyện tập

Iron displaces copper from copper(II) sulfate solution: $Fe + CuSO_4 -> FeSO_4 + Cu$. Write the two half-equations and identify the oxidising agent and the reducing agent.

Lời giải chi tiết

Oxidation: $Fe -> Fe^{2+} + 2e^-$. Reduction: $Cu^{2+} + 2e^- -> Cu$.
Fe is the **reducing agent** (it is oxidised); Cu^{2+} (in $CuSO_4$) is the **oxidising agent** (it is reduced).

Bài tập luyện tập

In the reaction $Cl_2 + 2KBr -> 2KCl + Br_2$, which species is the oxidising agent?

(A) Cl_2
(B) KBr
(C) KCl
(D) Br_2

Lời giải chi tiết

Cl_2 gains electrons ($Cl_2 + 2e^- -> 2Cl^-$), so it is reduced — the species reduced is the oxidising agent. **(A)**.

Bài tập luyện tập

(Supplement) Determine the oxidation state of chromium in the dichromate ion, $Cr_2O_7^{2-}$.

Lời giải chi tiết

(Supplement) Let the oxidation state of Cr be x. Oxygen is -2; overall ionic charge is -2:

$$2x + 7(-2) = -2 \Rightarrow 2x - 14 = -2 \Rightarrow 2x = 12 \Rightarrow x = +6.$$

Chromium is in the $+6$ oxidation state.

Bài tập luyện tập

(Supplement) Determine the oxidation state of nitrogen in nitric acid, HNO_3.

Lời giải chi tiết

(Supplement) H $= +1$, O $= -2$ each (three O atoms): $(+1) + x + 3(-2) = 0 \Rightarrow x - 5 = 0 \Rightarrow x = +5$.

Bài tập luyện tập

(Supplement) Determine the oxidation state of sulfur in sodium sulfite, Na_2SO_3.

Lời giải chi tiết

(Supplement) Na $= +1$ each (two Na), O $= -2$ each (three O): $2(+1) + x + 3(-2) = 0 \Rightarrow 2 + x - 6 = 0 \Rightarrow x = +4$.

Bài tập luyện tập

(Supplement) In $Fe_2O_3 + 3CO -> 2Fe + 3CO_2$, use oxidation states to identify which species is oxidised and which is reduced.

Lời giải chi tiết

(Supplement) Fe: $+3$ in $Fe_2O_3 \rightarrow 0$ in Fe — oxidation state *decreases* $\Rightarrow$ Fe is **reduced**.
C: $+2$ in CO $\rightarrow +4$ in CO_2 — oxidation state *increases* $\Rightarrow$ C is **oxidised**. (CO is the reducing agent; Fe_2O_3 is the oxidising agent.)

Bài tập luyện tập

(Supplement) Determine the oxidation state of carbon in carbon monoxide, CO, and in the carbonate ion, CO_3^{2-}, and comment on the difference.

Lời giải chi tiết

(Supplement) CO: $x + (-2) = 0 \Rightarrow x = +2$. CO_3^{2-}: $x + 3(-2) = -2 \Rightarrow x - 6 = -2 \Rightarrow x = +4$. Carbon is $+2$ in CO but $+4$ in CO_3^{2-} — consistent with CO being a reducing agent (Section 6.7, Fe_2O_3 example) that is readily oxidised further to the $+4$ state found in CO_2 and carbonates.

Bài tập luyện tập

(Supplement) In the thermite reaction, $2Al + Fe_2O_3 -> Al_2O_3 + 2Fe$, the oxidation state of iron changes from:

(A) 0 to $+3$
(B) $+3$ to 0
(C) $+2$ to 0
(D) 0 to $+2$

Lời giải chi tiết

(Supplement) Iron is $+3$ in Fe_2O_3 (since $2x + 3(-2) = 0 \Rightarrow x = +3$) and 0 in uncombined Fe metal — its oxidation state *decreases*, so iron is reduced. **(B)**. (Correspondingly, Al goes from 0 to $+3$ — it is oxidised and is the reducing agent; Fe_2O_3 is the oxidising agent.)

Bài tập luyện tập

In an experiment, excess dilute hydrochloric acid was added to marble chips in a flask on a mass balance. The mass lost was 0.40 g at 30 s and 0.70 g at 90 s. Calculate the average rate of reaction between 30 s and 90 s.

Lời giải chi tiết

$$\text{rate} = \frac{0.70 - 0.40}{90 - 30} = \frac{0.30}{60} = 0.0050 \text{ g/s}.$$

Bài tập luyện tập

In the disappearing-cross experiment with sodium thiosulfate and hydrochloric acid, the cross took 50 s to disappear at room temperature and only 25 s to disappear when the mixture was warmed. Calculate the ratio of the rate at the higher temperature to the rate at room temperature.

Lời giải chi tiết

Rate $\propto 1/t$: $\text{rate}_{\text{warm}}/\text{rate}_{\text{room}} = (1/25)/(1/50) = 50/25 = 2$. The reaction is twice as fast when warmed — consistent with the strong effect of temperature on rate (Section 6.1).

Bài tập luyện tập

(Supplement) For the equilibrium $\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightleftharpoons 2\text{HI}(\text{g})$, what is the effect of increasing the total pressure on the position of equilibrium?

(A) Shifts right, since there are fewer product molecules

(B) Shifts left, since there are more reactant molecules

(C) No effect, since the number of gas molecules is equal on both sides

(D) Cannot be determined without more information

Lời giải chi tiết

(Supplement) Gas molecules: $1 + 1 = 2$ on the left, 2 on the right — equal on both sides, so changing pressure does not shift this particular equilibrium. **(C)**.

Bài tập luyện tập

(Supplement) In the Haber process, ammonia is continuously liquefied and removed from the reaction mixture as it forms, and unreacted N_2/H_2 are recycled. Explain, using Le Chatelier's principle, why continuously removing NH_3 increases the overall conversion of N_2 and H_2 achieved by the plant.

Lời giải chi tiết

(Supplement) Removing NH_3 lowers its concentration below the equilibrium value, so by Le Chatelier's principle the equilibrium continually shifts to the **right** (the direction that produces more NH_3) to replace what has been removed. Recycling the unreacted N_2 and H_2 back through the reactor means that, over time, a much greater overall fraction of the original gases is converted to ammonia than the modest single-pass yield alone would suggest.

Bài tập luyện tập

When hydrogen is passed over heated copper(II) oxide, $CuO + H_2 -> Cu + H_2O$, which statement correctly identifies the oxidising agent using the oxygen/hydrogen definition?

(A) H_2 is the oxidising agent, since it gains oxygen

(B) CuO is the oxidising agent, since it loses oxygen and is reduced

(C) Cu is the oxidising agent, since it is a product

(D) H_2O is the oxidising agent, since it contains oxygen

Lời giải chi tiết

CuO loses oxygen (is reduced); the species reduced is always the oxidising agent. **(B)**.

Bài tập luyện tập

(Supplement) Determine the oxidation state of oxygen in barium peroxide, BaO_2, and explain why the usual value of -2 cannot be used here.

Lời giải chi tiết

(Supplement) Ba is a Group II metal, so Ba $= +2$. If oxygen were -2, the compound would sum to $2 + 2(-2) = -2 \neq 0$, which is impossible for a neutral compound — so BaO_2 must be a peroxide, with oxygen at -1: $2 + 2x = 0 \Rightarrow x = -1$. This matches the same exception seen in H_2O_2.

Bài tập luyện tập

Which of the following correctly states both definitions of *reduction*?

(A) Gain of electrons; gain of oxygen

(B) Loss of electrons; gain of oxygen

(C) Gain of electrons; loss of oxygen (or gain of hydrogen)

(D) Loss of electrons; loss of hydrogen

Lời giải chi tiết

Reduction is gain of electrons (OIL RIG) and, equivalently, loss of oxygen or gain of hydrogen. **(C)**.

Bài tập luyện tập

Which factor increases the rate of reaction mainly by increasing the *proportion* of collisions that are successful, rather than by making collisions more frequent?

(A) Increasing the concentration of a dissolved reactant

(B) Increasing the surface area of a solid reactant

(C) Adding a suitable catalyst

(D) Increasing the pressure of a gaseous reactant

Lời giải chi tiết

Concentration, surface area, and pressure all work by increasing how *often* particles collide, not by changing the fraction of collisions that succeed. A catalyst instead lowers the activation energy, so a greater *proportion* of collisions (at the same frequency) now succeed. **(C)**.

Bài tập luyện tập

Iron(II) chloride solution is oxidised by chlorine gas: $2FeCl_2 + Cl_2 -> 2FeCl_3$. Determine the oxidation state of iron before and after the reaction, and identify the oxidising agent.

Lời giải chi tiết

In $FeCl_2$: Cl $= -1$ each, so $x + 2(-1) = 0 \Rightarrow x = +2$. In $FeCl_3$: $x + 3(-1) = 0 \Rightarrow x = +3$. Iron's oxidation state increases from $+2$ to $+3$, so Fe^{2+} is **oxidised**; Cl_2 (which is reduced, $0 \to -1$) is the **oxidising agent**.

Bài tập luyện tập

(Supplement) Determine the oxidation state of chlorine in the chlorate(V) ion, ClO_3^-.

Lời giải chi tiết

(Supplement) Oxygen is -2 (three atoms); overall charge is -1: $x + 3(-2) = -1 \;\Rightarrow\; x - 6 = -1 \;\Rightarrow\; x = +5$.

Bài tập luyện tập

Silver nitrate solution is added to sodium chloride solution: $AgNO_3 + NaCl -> AgCl + NaNO_3$ (a white precipitate of AgCl forms). Is this a redox reaction? Justify your answer using oxidation states.

Lời giải chi tiết

(Supplement) Check each element's oxidation state on both sides: Ag is $+1$ in $AgNO_3$ and $+1$ in AgCl (unchanged); Cl is -1 in NaCl and -1 in AgCl (unchanged); Na stays $+1$; N and O in the nitrate ion are unchanged throughout. Since no element's oxidation state changes, this is **not** a redox reaction — it is a precipitation (ionic double decomposition) reaction, in which ions simply exchange partners without any electron transfer.

Bài tập luyện tập

A student plots volume of gas against time for the same reaction under three conditions: (i) original conditions, (ii) using a more concentrated acid, and (iii) using a catalyst with the original acid concentration. All three curves start at the origin and reach the same final volume. Which two curves would be expected to reach that final volume in the *same* time as each other, and why?

Lời giải chi tiết

Curves (ii) and (iii) would both be faster than (i), but there is no general reason for (ii) and (iii) to finish at exactly the *same* time as each other — concentration and catalysis speed up the

reaction by different, independent mechanisms (more frequent collisions vs. a greater proportion of successful collisions), so their effect on rate need not be numerically identical. All three curves do, however, reach the **same final volume**, since none of these changes affects the total amount of limiting reactant available.

Acids, Bases and Salts

Mục tiêu Unit: Định nghĩa axit, bazơ, kiềm; thang pH và các chất chỉ thị; phân biệt axit mạnh/yếu với đặc và loãng; phản ứng đặc trưng của axit với kim loại, oxit/hiđroxit và muối cacbonat; phân loại oxit (bazơ, axit, lưỡng tính, trung tính); quy trình điều chế muối tan (phương pháp dư chất rắn và chuẩn độ) và muối không tan (kết tủa, kèm phương trình ion); tính toán chuẩn độ axit–bazơ, kể cả với axit hai lần axit như H_2SO_4.

7.1 Acids, bases and alkalis

7.1.1 Definitions and common examples

An **acid** is a substance that produces hydrogen ions, H^+, when dissolved in water. Common laboratory acids include hydrochloric acid (HCl), sulfuric acid (H_2SO_4), nitric acid (HNO_3) and the weak organic acid ethanoic acid (CH_3COOH). A **base** is a substance that neutralises an acid by reacting with H^+ ions; metal oxides, metal hydroxides and (in a slightly different sense) metal carbonates all behave as bases towards acids. A base that is **soluble** in water is called an **alkali**: alkalis produce hydroxide ions, OH^-, in solution. Common alkalis include sodium hydroxide (NaOH), potassium hydroxide (KOH), calcium hydroxide ($Ca(OH)_2$, limewater) and aqueous ammonia ($NH_3(aq)$).

Khái niệm cốt lõi

Acid: dissolves in water to give $H^+(aq)$.
Base: any substance (soluble or not) that neutralises an acid by combining with H^+ — typically a metal oxide, metal hydroxide, or metal carbonate.
Alkali: a base that is *soluble*, giving free $OH^-(aq)$ in solution. All alkalis are bases, but not every base is an alkali — copper(II) oxide, CuO, is a base (it neutralises acids) but is *insoluble*, so it is not an alkali.

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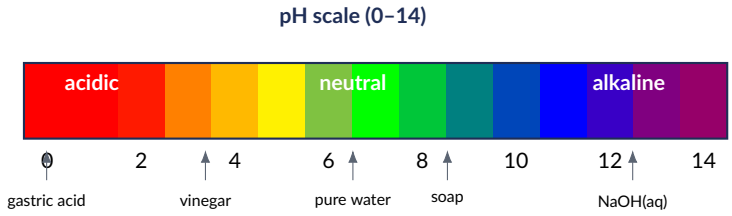
Axit tạo ion H^+ khi tan trong nước. **Bazơ** là chất trung hoà được axit bằng cách phản ứng với ion H^+ — thường là oxit kim loại, hiđroxit kim loại, hoặc muối cacbonat. **Kiềm** là bazơ **tan** trong nước, tạo ion OH^- tự do. Mọi kiềm đều là bazơ, nhưng không phải bazơ nào cũng là kiềm — ví dụ CuO là bazơ (trung hoà axit) nhưng không tan nên không phải là kiềm.

Category	Common examples
Acids	HCl (hydrochloric), H_2SO_4 (sulfuric), HNO_3 (nitric) — all strong; CH_3COOH (ethanoic) — weak
Insoluble bases (not alkalis)	CuO, MgO, ZnO, Fe_2O_3 (metal oxides); insoluble metal hydroxides and carbonates
Alkalis (soluble bases)	NaOH, KOH, $Ca(OH)_2$ (limewater), $NH_3(aq)$ (aqueous ammonia)

7.1.2 The pH scale and indicators

The **pH scale** runs from 0 to 14 and measures how acidic or alkaline a solution is. A pH below 7 is **acidic** (the lower the value, the more concentrated the free H^+ ions); a pH of exactly 7 is **neutral** (pure water); a pH above 7 is **alkaline** (the higher the value, the more concentrated the free OH^- ions).



Universal indicator gives a colour across the whole pH range: red/orange (strongly acidic) through yellow and green (neutral) to blue and violet (strongly alkaline).

Indicator colours

Indicator	In acid	Neutral	In alkali
Litmus	Red	Purple	Blue
Universal indicator	Red → orange/yellow	Green	Blue → purple/violet
Phenolphthalein	Colourless	Colourless	Pink
Methyl orange	Red	Orange	Yellow

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Thang pH từ 0–14: pH < 7 là axit (càng nhỏ càng nhiều H^+), pH $= 7$ trung tính (nước tinh khiết), pH > 7 là kiềm (càng lớn càng nhiều OH^-). Chất chỉ thị vạn năng đổi màu theo cả thang pH; quỳ tím chỉ có 2 màu (đỏ/xanh); phenolphthalein không màu trong axit/trung tính và hồng trong kiềm; methyl da cam đỏ trong axit và vàng trong kiềm.

7.2 Strong acids and weak acids (Supplement)

7.2.1 Degree of ionisation

(Supplement) When an acid dissolves in water, its molecules may split up (**ionise**) to release H^+ ions. A **strong** acid (e.g. HCl, H_2SO_4, HNO_3) ionises *completely* — essentially every molecule splits into ions. A **weak** acid (e.g. CH_3COOH, carbonic acid H_2CO_3) ionises only *partially*: most molecules remain un-ionised, existing in a dynamic equilibrium with the small proportion of ions formed.

$HCl -> H^+ + Cl^-$ (complete ionisation) $\qquad CH_3COOH \rightleftharpoons H^+ + CH_3COO^-$ (partial ionisation)

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Axit **mạnh** (như HCl) phân li **hoàn toàn** thành ion trong nước — hầu như mọi phân tử đều tách ra. Axit **yếu** (như CH_3COOH) chỉ phân li **một phần**, phần lớn phân tử vẫn tồn tại ở dạng chưa phân li, ở trạng thái cân bằng động với một lượng nhỏ ion.

7.2.2 Strong/weak versus concentrated/dilute

(Supplement) **Strong/weak** describes the *degree of ionisation* — a fixed chemical property of a particular acid, unaffected by dilution. **Concentrated/dilute** describes the *amount of acid dissolved per unit volume* of solution (mol/dm^3) — this can be changed at will simply by adding or removing water. The two ideas are completely independent: it is perfectly possible to have a concentrated weak acid or a dilute strong acid.

(!) Lỗi thường gặp: Students very often confuse **strong/weak** with **concentrated/dilute**. They are not the same thing: *strong* and *weak* refer to how completely the acid ionises (a fixed property of the acid itself), while *concentrated* and *dilute* refer to how much acid is dissolved in a given volume of water (which can be changed by adding water). A dilute solution of a strong acid can still contain a higher concentration of free H^+ ions than a concentrated solution of a weak acid. Never write "a weak acid is a dilute acid" — a bottle of concentrated ethanoic acid is still a *weak* acid; diluting hydrochloric acid with water does not turn it into a weak acid, only into a more dilute strong acid.

VN **GIẢI THÍCH TIẾNG VIỆT**

Đây là lỗi rất hay gặp: **mạnh/yếu** nói về **mức độ phân li** (tính chất cố định của axit); **đặc/loãng** nói về **lượng axit hoà tan trong một thể tích nước** (có thể thay đổi bằng cách thêm nước). Axit loãng nhưng mạnh vẫn có thể có nhiều ion H^+ hơn axit đặc nhưng yếu. Axit axetic đặc vẫn là axit **yếu**; pha loãng HCl chỉ tạo ra axit mạnh loãng hơn, không biến nó thành axit yếu.

7.2.3 Comparing pH, conductivity and reaction rate

(Supplement) At *equal* concentration (say, both 1.0 mol/dm^3), a strong acid and a weak acid differ in three measurable ways: the strong acid has a **lower pH** (more free H^+), a **higher electrical conductivity** (more mobile ions to carry charge), and reacts **faster** with reactive metals or carbonates (a higher concentration of H^+ collides with the metal/carbonate surface more often per second).

Ví dụ mẫu · Comparing HCl and CH_3COOH at equal concentration

(Supplement) $1.0\,\text{mol}/\text{dm}^3$ hydrochloric acid and $1.0\,\text{mol}/\text{dm}^3$ ethanoic acid are compared side by side. Predict, with reasons, how they differ in (a) pH, (b) rate of reaction with magnesium ribbon, (c) electrical conductivity.

(a) pH: HCl ionises completely, so $1.0\,\text{mol}/\text{dm}^3$ HCl gives close to $1.0\,\text{mol}/\text{dm}^3$ of free H^+, so its pH is close to 0. CH_3COOH ionises only partially, so the same nominal concentration gives far fewer free H^+ ions — its pH is noticeably higher (still below 7, but well above that of the HCl).

(b) Rate with magnesium: $Mg + 2HCl -> MgCl_2 + H_2$ and $Mg + 2CH_3COOH -> (CH_3COO)_2Mg + H_2$ both occur, but the rate of hydrogen production depends on the frequency of collisions between free H^+ ions and the metal surface. Since HCl supplies far more free H^+ at the same nominal concentration, it reacts **faster**.

(c) Conductivity: conductivity depends on the concentration of mobile ions present. The fully-ionised HCl conducts **better** than the partially-ionised CH_3COOH at equal nominal concentration.

Distinguishing strong and weak acids experimentally

(Supplement) Three simple experiments can compare a strong acid and a weak acid at the same nominal concentration: (1) measure the **pH** directly with universal indicator or a pH probe — the strong acid reads a lower pH; (2) react a fixed mass of magnesium ribbon (or marble chips) with each acid and measure the **volume of gas collected in a fixed time** using a gas syringe, or time how long a fixed mass takes to fully react — the strong acid reacts faster; (3) dip inert electrodes connected to a bulb and an ammeter into each acid — the strong acid gives a **brighter bulb** and a higher current reading, showing it conducts electricity better.

VN **GIẢI THÍCH TIẾNG VIỆT**

(Supplement) Có thể phân biệt axit mạnh và axit yếu (cùng nồng độ danh nghĩa) bằng 3 thí nghiệm đơn giản: (1) đo trực tiếp pH bằng giấy chỉ thị vạn năng hoặc máy đo pH — axit mạnh cho pH thấp hơn; (2) cho phản ứng với cùng khối lượng kim loại (như magie) và đo thể tích khí sinh ra trong cùng thời gian — axit mạnh phản ứng nhanh hơn; (3) đo độ dẫn điện bằng mạch điện có bóng đèn và ampe kế — axit mạnh dẫn điện tốt hơn (đèn sáng hơn, dòng điện lớn hơn).

7.3 Reactions of acids

7.3.1 Reaction with metals

Dilute acids react with reactive metals (e.g. magnesium, zinc, iron — metals above copper in the reactivity series) to give a salt and hydrogen gas, with visible **effervescence** (bubbling) and a rise in temperature (exothermic):

$$\text{acid} + \text{metal} \rightarrow \text{salt} + \text{hydrogen}, \qquad Mg + 2HCl -> MgCl_2 + H_2, \qquad Zn + H_2SO_4 -> ZnSO_4 + H_2.$$

The gas produced is confirmed as hydrogen using a lighted splint, which gives a characteristic "squeaky pop".

7.3.2 Reaction with bases and metal oxides (neutralisation)

Acids react with bases — metal oxides or metal hydroxides — in a **neutralisation** reaction to form a salt and water only, with no gas produced (only a gentle rise in temperature):

$$\text{acid} + \text{base} \rightarrow \text{salt} + \text{water}, \qquad CuO + H_2SO_4 -> CuSO_4 + H_2O, \qquad NaOH + HCl -> NaCl + H_2O.$$

7.3.3 Reaction with carbonates

Acids react with metal carbonates (soluble or insoluble) to give a salt, water, and carbon dioxide gas, again with effervescence and a temperature rise:

$$\text{acid} + \text{carbonate} \rightarrow \text{salt} + \text{water} + \text{carbon dioxide}, \qquad CaCO_3 + 2HCl -> CaCl_2 + H_2O + CO_2.$$

The gas is confirmed as CO_2 because it turns limewater milky/cloudy.

Naming salts from the parent acid:

Acid	Salt name ending
Hydrochloric acid (HCl)	**chloride**
Sulfuric acid (H_2SO_4)	**sulfate**
Nitric acid (HNO_3)	**nitrate**
Carbonic acid (H_2CO_3)	**carbonate** (or **hydrogencarbonate** if only half-neutralised)
Ethanoic acid (CH_3COOH)	**ethanoate**

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Axit + kim loại → muối + khí hiđro (sủi bọt khí, toả nhiệt); axit + bazơ/oxit kim loại → muối + nước (trung hoà, không có khí); axit + muối cacbonat → muối + nước + khí CO_2 (sủi bọt, làm đục nước vôi trong). Tên muối theo gốc axit: HCl →clorua, H_2SO_4 →sunfat, HNO_3 →nitrat, H_2CO_3 →cacbonat.

7.3.4 Testing for the gases produced

Gas	Test	Positive result
Hydrogen, H_2	Hold a lighted splint at the mouth of the test tube	A **squeaky pop** is heard
Carbon dioxide, CO_2	Bubble the gas through limewater, $Ca(OH)_2(aq)$	Limewater turns **milky/cloudy**

VN **GIẢI THÍCH TIẾNG VIỆT**

Khí hiđro được nhận biết bằng que đóm đang cháy đưa vào miệng ống nghiệm — có tiếng nổ nhỏ, lách tách ("squeaky pop"). Khí CO_2 được nhận biết bằng cách dẫn qua nước vôi trong — nước vôi hoá đục.

Ví dụ mẫu · Mass of gas from a carbonate reaction

Excess dilute hydrochloric acid is added to $5.30\,\text{g}$ of sodium carbonate, Na_2CO_3 ($M_r = 106$): $Na_2CO_3 + 2HCl -> 2NaCl + H_2O + CO_2$. Calculate the mass of carbon dioxide gas released.

$$n(Na_2CO_3) = \frac{5.30}{106} = 0.0500 \text{ mol}.$$

Mole ratio $Na_2CO_3 : CO_2 = 1:1$, so $n(CO_2) = 0.0500$ mol. Using $M_r(CO_2) = 44$:

$$m(CO_2) = 0.0500 \times 44 = 2.20 \text{ g}.$$

7.4 Oxides

7.4.1 Basic oxides

Basic oxides are metal oxides that react with acids (but not with alkalis) to form a salt and water only — they behave purely as bases. Examples: Na_2O, MgO, CuO, PbO, CaO, Fe_2O_3.

$$Na_2O + 2HCl -> 2NaCl + H_2O, \qquad MgO + 2HCl -> MgCl_2 + H_2O.$$

7.4.2 Acidic oxides

Acidic oxides are non-metal oxides that react with alkalis (but not with acids) to form a salt and water, and typically dissolve in water to give an acidic solution. Examples: CO_2, SO_2, SO_3, P_2O_5, SiO_2.

$$CO_2 + 2NaOH -> Na_2CO_3 + H_2O, \qquad SO_3 + 2NaOH -> Na_2SO_4 + H_2O.$$

7.4.3 Amphoteric oxides

Amphoteric oxides react with *both* acids and alkalis — acting as a base towards an acid, and as an acid towards an alkali. The classic examples are Al_2O_3 and ZnO.

$$Al_2O_3 + 6HCl -> 2AlCl_3 + 3H_2O \qquad \text{(acting as a base)}$$

$$Al_2O_3 + 2NaOH -> 2NaAlO_2 + H_2O \qquad \text{(acting as an acid)}$$

7.4.4 Neutral oxides (Supplement)

(Supplement) **Neutral oxides** react with *neither* acids nor alkalis — they are neither acidic nor basic. Examples: carbon monoxide (CO), nitrogen monoxide (NO), dinitrogen oxide (N_2O). (Water, H_2O, is also neutral, though it is not usually classed alongside these gases.)

Oxide	Class	Example reaction
Na_2O	Basic	$Na_2O + 2HCl -> 2NaCl + H_2O$
MgO	Basic	$MgO + 2HCl -> MgCl_2 + H_2O$
PbO	Basic	$PbO + 2HNO_3 -> Pb(NO_3)_2 + H_2O$
CO_2	Acidic	$CO_2 + 2NaOH -> Na_2CO_3 + H_2O$
SO_3	Acidic	$SO_3 + 2NaOH -> Na_2SO_4 + H_2O$
P_2O_5	Acidic	$P_2O_5 + 6NaOH -> 2Na_3PO_4 + 3H_2O$
Al_2O_3	Amphoteric	reacts with *both* HCl and NaOH (above)
ZnO	Amphoteric	$ZnO + H_2SO_4 -> ZnSO_4 + H_2O$; $ZnO + 2NaOH -> Na_2ZnO_2 + H_2O$
CO	Neutral (Supplement)	no reaction with acid or alkali
NO	Neutral (Supplement)	no reaction with acid or alkali

Oxide classification: basic oxides react with acids only; acidic oxides react with alkalis only; amphoteric oxides react with both; neutral oxides react with neither.

VN **GIẢI THÍCH TIẾNG VIỆT**

Oxit **bazơ** (oxit kim loại) chỉ phản ứng với axit; oxit **axit** (oxit phi kim) chỉ phản ứng với kiềm; oxit **lưỡng tính** phản ứng được với **cả hai** (ví dụ Al_2O_3, ZnO); (Supplement) oxit **trung tính** không phản ứng với cái nào cả (ví dụ CO, NO).

Ví dụ mẫu · Classifying several oxides at once

Classify each oxide below as basic, acidic, amphoteric or neutral, giving a brief reason.

Oxide	Classification	Reasoning
K_2O	Basic	metal oxide (Group I) — reacts only with acids
SO_3	Acidic	non-metal oxide — reacts only with alkalis
ZnO	Amphoteric	known exception — reacts with *both* acids and alkalis
CO	Neutral (Supplement)	known exception — reacts with neither
Fe_2O_3	Basic	metal oxide — reacts with acids: $Fe_2O_3 + 6HCl -> 2FeCl_3 + 3H_2O$
N_2O_5	Acidic	non-metal oxide — reacts with alkalis: $N_2O_5 + 2NaOH -> 2NaNO_3 + H_2O$

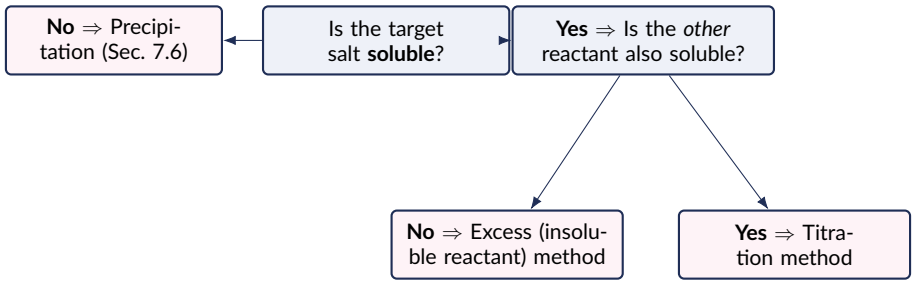
General rule of thumb: metal oxide ⇒ basic, non-metal oxide ⇒ acidic — **unless** it is one of the well-known amphoteric (Al_2O_3, ZnO) or neutral (CO, NO, N_2O) exceptions, which must simply be learned.

7.5 Preparing soluble salts

Choosing a method

1. **Is the target salt soluble or insoluble?** (See the solubility rules in Section 7.6.) If insoluble, use **precipitation** instead of either method below.
2. **If soluble, and one reactant is an insoluble solid** — a reactive metal, an insoluble metal oxide/hydroxide, or an insoluble carbonate — use the **excess (insoluble reactant) method**.
3. **If soluble, and both reactants are themselves soluble** — typically an alkali + an acid, or a soluble carbonate + an acid — there is no solid excess to filter off, so use the **titration**

method.



Decision tree for choosing a salt-preparation method: check solubility of the target salt first, then (if soluble) whether both reactants are themselves soluble.

7.5.1 The excess (insoluble reactant) method

Used when one reactant is an insoluble solid (a reactive metal, insoluble base/oxide, or insoluble carbonate) and the other is a soluble acid.

1. Warm the dilute acid gently (this speeds up the reaction; do not boil).
2. Add the insoluble solid to the acid *a little at a time*, *with stirring*, until no more dissolves and a slight excess of solid remains undissolved — this guarantees *all* the acid has reacted, so the salt solution contains no leftover acid.
3. **Filter** the mixture to remove the unreacted excess solid, collecting the salt solution as the filtrate.
4. Gently heat the filtrate to evaporate off some of the water, until the solution is saturated (tested by dipping a glass rod in and seeing crystals form on cooling, or evaporating to about one third of the volume).
5. Leave the hot saturated solution to **cool slowly** so that crystals of the salt grow.
6. **Filter** off the crystals, wash them with a little cold distilled water (to remove surface impurities without dissolving much of the crystals), and dry them between sheets of filter paper (or in a low-temperature oven).

Ví dụ mẫu · Preparing hydrated copper(II) sulfate crystals

Describe how to prepare a pure, dry sample of hydrated copper(II) sulfate crystals, $CuSO_4.5H_2O$, from black copper(II) oxide powder and $50.0\,cm^3$ of $1.00\,mol/dm^3$ dilute sulfuric acid, and calculate the maximum mass of crystals obtainable.

Method (excess method, since CuO is an insoluble base):

1. Warm the dilute sulfuric acid; add black CuO powder a little at a time, stirring, until it is in slight excess (the mixture is blue and some black solid remains undissolved) — this ensures all the acid has reacted: $CuO + H_2SO_4 -> CuSO_4 + H_2O$.
2. **Filter** to remove the excess (unreacted) CuO, collecting the blue filtrate ($CuSO_4$ solution).
3. Gently heat the filtrate to evaporate water until it is a hot, saturated solution.
4. Leave to **cool slowly** so that blue crystals of $CuSO_4.5H_2O$ grow.
5. **Filter** off the crystals, wash with a little cold distilled water, and dry between filter paper.

Calculation:

$$n(H_2SO_4) = 1.00 \times \frac{50.0}{1000} = 0.0500 \text{ mol}.$$

Mole ratio H_2SO_4 : $CuSO_4$ = 1 : 1, so $n(CuSO_4.5H_2O) = 0.0500$ mol. Using

$M_r(\text{CuSO}_4.5\text{H}_2\text{O}) = 64 + 32 + 4(16) + 5(18) = 250$:

$$m = 0.0500 \times 250 = 12.5 \text{ g}.$$

7.5.2 The titration method

Used when *both* reactants are soluble (typically an alkali reacting with an acid), so there is no solid excess left to filter off. The exact volumes that react together must first be found by titration (Section 7.7), using an indicator to spot the end point.

1. Titrate the alkali against the acid using a suitable indicator (e.g. phenolphthalein) to find the volumes that react exactly, and record the mean of concordant, accurate titres.
2. Repeat the reaction using the *same measured volumes* of alkali and acid, but **without** any indicator, so that no indicator dye contaminates the final salt.
3. Evaporate the resulting salt solution to a saturated solution, then leave to cool and **crystallise**.
4. **Filter** off the crystals, wash with a little cold distilled water, and dry between filter paper.

The full step-by-step titration procedure (rinsing, rough and accurate titrations, concordant results) and the apparatus diagram are given in Section 7.7.

VN **GIẢI THÍCH TIẾNG VIỆT**

Sơ đồ chọn phương pháp điều chế muối: (1) muối tan hay không tan? Không tan → dùng **kết tủa**. (2) Nếu tan và một chất là chất rắn không tan (kim loại, oxit/hiđroxit không tan, cacbonat không tan) → dùng **phương pháp dư chất rắn**: cho dư chất rắn vào axit, lọc bỏ phần dư, cô cạn và kết tinh dịch lọc. (3) Nếu tan và **cả hai** chất phản ứng đều tan (ví dụ kiềm + axit) → không có chất rắn dư để lọc, phải dùng **phương pháp chuẩn độ**: chuẩn độ có chỉ thị để tìm thể tích phản ứng vừa đủ, rồi lặp lại không dùng chỉ thị và kết tinh sản phẩm.

(!) Lỗi thường gặp: A frequent mistake is choosing the **wrong method** for a given pair of reactants. If *either* reactant is insoluble (a metal, an insoluble oxide/hydroxide, or an insoluble carbonate), use the **excess method** — titration is unnecessary and wasteful here, since simply filtering off the excess solid already guarantees an acid-free product. If *both* reactants are soluble (e.g. NaOH and HCl, or KOH and H_2SO_4), the excess method cannot work — there is no insoluble excess to filter off, so exact volumes *must* be found by **titration** first. And if the desired salt itself is **insoluble** (e.g. $BaSO_4$, $PbCl_2$, AgCl), neither of these two methods applies at all — use **precipitation** (Section 7.6) instead.

7.6 Preparing insoluble salts by precipitation

An insoluble salt cannot be made by either method in Section 7.5: the excess method would leave nothing dissolved to crystallise, and titration requires a soluble product. Instead, two *soluble* solutions are chosen so that, when mixed, their ions combine to form the insoluble salt, which appears immediately as a precipitate.

7.6.1 Procedure

1. Mix appropriate volumes of two soluble solutions, each supplying one of the two ions needed to form the insoluble salt.
2. **Filter** the mixture to collect the solid precipitate.
3. **Wash** the precipitate on the filter paper with a little distilled water, to remove soluble impurities trapped within it (e.g. the other soluble salt formed as a by-product).

4. **Dry** the precipitate, e.g. between sheets of filter paper or in a low-temperature oven.

7.6.2 Full and ionic equations (Supplement)

(Supplement) A full equation for a precipitation reaction shows all the species as formula units; an **ionic equation** shows only the ions that actually combine to form the precipitate, omitting the **spectator ions** (ions that appear unchanged, in the same form, on both sides).

(Supplement) **Balancing an ionic equation:** both the *atoms* and the overall *charge* must balance on each side. For $Pb^{2+}(aq) + SO_4^{2-}(aq) -> PbSO_4(s)$, the left side has one $2+$ ion and one $2-$ ion (net charge zero), matching the neutral solid on the right (net charge zero).

Ví dụ mẫu · Preparing lead(II) sulfate by precipitation

(Supplement) Describe how to prepare a pure, dry sample of lead(II) sulfate from lead(II) nitrate solution and sodium sulfate solution, and give the full and ionic equations.

Method: mix aqueous lead(II) nitrate with aqueous sodium sulfate; a white precipitate of lead(II) sulfate forms immediately. **Filter** the mixture; **wash** the residue on the filter paper with a little distilled water (to remove soluble sodium nitrate); **dry** the precipitate between sheets of filter paper.

Full equation:

$$Pb(NO_3)_2(aq) + Na_2SO_4(aq) -> PbSO_4(s) + 2NaNO_3(aq).$$

Na^+ and NO_3^- appear unchanged on both sides, so they are spectator ions and are omitted from the **ionic equation**:

$$Pb^{2+}(aq) + SO_4^{2-}(aq) -> PbSO_4(s).$$

7.6.3 Solubility rules

Solubility rules (all common sodium, potassium and ammonium salts are soluble):

Salt family	Generally	Main exceptions (insoluble)
Nitrates	all soluble	none
Chlorides	mostly soluble	AgCl, $PbCl_2$
Sulfates	mostly soluble	$BaSO_4$, $PbSO_4$, $CaSO_4$
Carbonates	mostly insoluble	except Group I carbonates (e.g. Na_2CO_3, K_2CO_3) and $(NH_4)_2CO_3$

VN **GIẢI THÍCH TIẾNG VIỆT**

Quy tắc độ tan: mọi muối natri, kali và amoni đều tan; mọi **nitrat** đều tan; hầu hết **clorua** tan, trừ AgCl và $PbCl_2$; hầu hết **sunfat** tan, trừ $BaSO_4$, $PbSO_4$, $CaSO_4$; hầu hết **cacbonat** không tan, trừ cacbonat nhóm I và amoni cacbonat.

Ví dụ mẫu · Predicting a precipitate — will one form?

For each pair of solutions below, predict whether mixing them produces a precipitate.

(a) Barium chloride and sodium sulfate: $BaCl_2(aq) + Na_2SO_4(aq) -> BaSO_4(s) + 2NaCl(aq)$. Barium sulfate is one of the sulfate exceptions (insoluble), so a **white precipitate** of $BaSO_4$ forms.

(b) Potassium nitrate and sodium chloride: the possible new combinations are KCl and $NaNO_3$

— both are soluble (all nitrates soluble; KCl is not one of the chloride exceptions). **No precipitate** forms; the ions simply remain mixed in solution.

7.6.4 Testing for anions by precipitation

The solubility rules above are put to direct use in the laboratory to **identify** which anion is present in an unknown solution: a suitable soluble reagent is added, and the appearance (or absence) of a precipitate confirms the ion present.

Ion tested	Test	Positive result
Carbonate, CO_3^{2-}	Add dilute acid (e.g. HCl)	Effervescence; gas turns limewater milky (CO_2)
Sulfate, SO_4^{2-}	Acidify with dilute HCl, then add $BaCl_2(aq)$	White precipitate ($BaSO_4$)
Chloride, Cl^-	Acidify with dilute HNO_3, then add $AgNO_3(aq)$	White precipitate (AgCl)

VN **GIẢI THÍCH TIẾNG VIỆT**

Quy tắc độ tan được dùng để **nhận biết** ion âm trong dung dịch chưa biết: cacbonat — cho axit loãng, sủi bọt khí làm đục nước vôi; sunfat — axit hoá bằng HCl loãng rồi thêm $BaCl_2(aq)$, xuất hiện kết tủa trắng $BaSO_4$; clorua — axit hoá bằng HNO_3 loãng rồi thêm $AgNO_3(aq)$, xuất hiện kết tủa trắng AgCl.

Ví dụ mẫu · Identifying an unknown salt

A colourless solution is known to be one of sodium carbonate, sodium sulfate or sodium chloride. Describe tests that would identify which salt is present.

Step 1: add dilute hydrochloric acid to a sample. If **effervescence** occurs and the gas turns limewater milky, the salt is **sodium carbonate** ($Na_2CO_3 + 2HCl -> 2NaCl + H_2O + CO_2$).

Step 2: if there is no effervescence, split the remaining solution into two portions. To the first, add dilute HCl followed by $BaCl_2(aq)$: a **white precipitate** confirms **sodium sulfate** ($Na_2SO_4 + BaCl_2 -> BaSO_4\downarrow + 2NaCl$).

Step 3: to the second portion, add dilute HNO_3 followed by $AgNO_3(aq)$: a **white precipitate** confirms **sodium chloride** ($NaCl + AgNO_3 -> AgCl\downarrow + NaNO_3$). If neither test 2 nor test 3 gives a precipitate, the original salt must have been the carbonate (confirmed already in Step 1).

7.7 Titration calculations

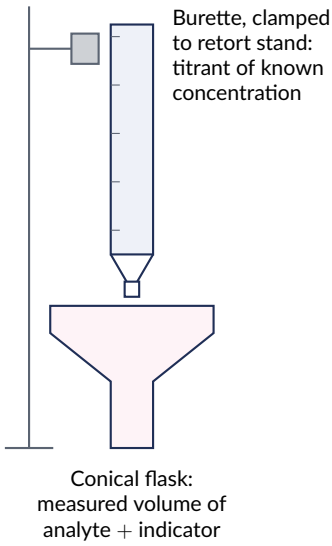
7.7.1 Carrying out a titration

A titration finds the exact volumes of two solutions that react completely with each other, using an indicator to signal the **end point**.

Step-by-step titration procedure

1. **Rinse** the burette with a little of the solution it will hold (the titrant), and rinse the pipette with a little of the solution it will measure (the analyte) — this stops residual water diluting the solutions. The conical flask, by contrast, is rinsed only with **distilled water**: any leftover solution inside it would add extra, uncounted moles of reactant.
2. Use a pipette (with a pipette filler) to measure an exact, fixed volume of one solution into the conical flask, and add a few drops of a suitable indicator.

3. Fill the burette with the other solution up to (or just above) the $0.00\,\text{cm}^3$ mark, reading the bottom of the meniscus at eye level, and record this initial reading.
4. Perform a quick **rough titration**: add titrant fairly rapidly while continuously swirling the flask, until the indicator just permanently changes colour. Record this rough titre to the nearest whole cm^3 — it is only a guide and is *not* included in the final average.
5. Repeat with fresh solution for **accurate titrations**: add titrant quickly to within about $2\,\text{cm}^3$ of the rough end point, then add it *drop by drop*, swirling constantly, until one drop causes a permanent colour change (the end point). Record each accurate burette reading to the nearest $0.05\,\text{cm}^3$ or $0.10\,\text{cm}^3$.
6. Repeat the accurate titration until at least two **concordant results** are obtained — titres agreeing with each other to within $0.10\,\text{cm}^3$.
7. Calculate the **mean of the concordant titres only** (never the rough titre, and never a titre lying outside the concordant range) and use this mean volume in all further calculations.



Titration apparatus: a burette, clamped to a retort stand, delivers titrant dropwise into a conical flask containing a pipetted volume of analyte and a few drops of indicator, on a white tile so the end-point colour change is clear.

VN **GIẢI THÍCH TIẾNG VIỆT**

Quy trình chuẩn độ: tráng burette bằng chính dung dịch sẽ chứa (không tráng bằng nước, tránh pha loãng); tráng pipet bằng dung dịch sẽ hút; riêng bình tam giác chỉ tráng bằng nước cất. Chuẩn độ thô (rough) để ước lượng nhanh điểm kết thúc, ghi đến số nguyên cm^3 và KHÔNG tính vào trung bình; sau đó chuẩn độ chính xác (nhỏ từng giọt gần điểm cuối), lặp lại đến khi có ít nhất hai kết quả **phù hợp** (chênh lệch $\leq 0.10\ \text{cm}^3$). Chỉ lấy **trung bình các lần phù hợp** để tính toán.

7.7.2 Basic mole-ratio calculations

Every titration calculation follows the same three steps: (1) find moles of the reactant whose concentration and volume are both known, using $n = c \times V$ (with V in dm^3); (2) use the mole ratio from the balanced equation to find moles of the other reactant; (3) rearrange $n = cV$ to find the unknown quantity.

Ví dụ mẫu · Worked example

$25.0\,\text{cm}^3$ of $0.100\,\text{mol/dm}^3$ sodium hydroxide is exactly neutralised by $20.0\,\text{cm}^3$ of hydrochloric acid: $\text{NaOH} + \text{HCl} -> \text{NaCl} + \text{H}_2\text{O}$. Calculate the concentration of the acid.

$n(\text{NaOH}) = 0.100 \times \dfrac{25.0}{1000} = 0.00250$ mol. Mole ratio NaOH : HCl $= 1:1$, so $n(\text{HCl}) = 0.00250$ mol.

$$c(\text{HCl}) = \frac{0.00250}{20.0/1000} = \frac{0.00250}{0.0200} = 0.125\ \text{mol/dm}^3.$$

7.7.3 Diprotic acids

(Supplement) Sulfuric acid, H_2SO_4, is **diprotic**: each molecule can release *two* H^+ ions. This means the mole ratio between H_2SO_4 and a monobasic alkali (like NaOH or KOH) is $1:2$, not $1:1$.

Ví dụ mẫu · Worked example

$20.0\,\text{cm}^3$ of $0.050\,\text{mol/dm}^3$ sulfuric acid is exactly neutralised by $25.0\,\text{cm}^3$ of sodium hydroxide solution: $\text{H}_2\text{SO}_4 + 2\text{NaOH} -> \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O}$. Calculate the concentration of the NaOH.

$n(\text{H}_2\text{SO}_4) = 0.050 \times \dfrac{20.0}{1000} = 0.00100$ mol. Mole ratio H_2SO_4 : NaOH $= 1:2$, so $n(\text{NaOH}) = 2 \times 0.00100 = 0.00200$ mol.

$$c(\text{NaOH}) = \frac{0.00200}{25.0/1000} = 0.0800\ \text{mol/dm}^3.$$

(!) Lỗi thường gặp: Forgetting the **mole ratio** from the balanced equation is one of the most common titration errors, especially with a diprotic acid like H_2SO_4. Sulfuric acid needs *twice* as many moles of a monobasic alkali as hydrochloric acid does, because each H_2SO_4 molecule supplies 2 H^+ ions ($\text{H}_2\text{SO}_4 + 2\text{NaOH} -> \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O}$), whereas HCl supplies only 1 ($\text{HCl} + \text{NaOH} -> \text{NaCl} + \text{H}_2\text{O}$). Always write the balanced equation first and read the mole ratio directly from its coefficients — never assume a 1:1 ratio by default.

VN **GIẢI THÍCH TIẾNG VIỆT**

H_2SO_4 là axit **hai lần axit** (diprotic): mỗi phân tử giải phóng **2** ion H^+, nên tỉ lệ mol với kiềm một lần bazơ (như NaOH) là $1:2$, không phải $1:1$. Lỗi phổ biến nhất trong tính toán chuẩn độ là quên tỉ lệ mol này — luôn viết phương trình cân bằng trước rồi mới đọc tỉ lệ mol từ hệ số.

7.7.4 Combined titration and mass-of-salt problems

A common exam-style question combines a titration calculation with a further mass calculation: first find the unknown concentration, then use the resulting moles of salt to find the mass of solid that could be crystallised out.

Ví dụ mẫu · Full titration + mass-of-salt calculation

$25.0\,\text{cm}^3$ of $0.150\,\text{mol/dm}^3$ potassium hydroxide solution is exactly neutralised by $15.0\,\text{cm}^3$ of dilute sulfuric acid: $2\text{KOH} + \text{H}_2\text{SO}_4 -> \text{K}_2\text{SO}_4 + 2\text{H}_2\text{O}$. (a) Calculate the concentration of the sulfuric acid. (b) If the resulting solution is evaporated to dryness, calculate the maximum mass of solid potassium sulfate obtained ($M_r(\text{K}_2\text{SO}_4) = 174$).

Step 1 — moles of KOH:

$$n(\text{KOH}) = 0.150 \times \frac{25.0}{1000} = 0.003750 \text{ mol}.$$

Step 2 — moles of H_2SO_4 (mole ratio KOH : $H_2SO_4 = 2:1$):

$$n(\text{H}_2\text{SO}_4) = \frac{0.003750}{2} = 0.001875 \text{ mol}.$$

(a) Concentration of H_2SO_4:

$$c(\text{H}_2\text{SO}_4) = \frac{0.001875}{15.0/1000} = \frac{0.001875}{0.0150} = 0.125 \text{ mol/dm}^3.$$

(b) Mass of K_2SO_4: mole ratio H_2SO_4 : $K_2SO_4 = 1:1$, so $n(\text{K}_2\text{SO}_4) = 0.001875$ mol.

$$m(\text{K}_2\text{SO}_4) = 0.001875 \times 174 = 0.326 \text{ g } (3 \text{ s.f.}).$$

Ví dụ mẫu · Titration, dilution and percentage purity

A $1.325\,\text{g}$ sample of impure sodium carbonate is dissolved in water and made up to exactly $250\,\text{cm}^3$ of solution in a volumetric flask. A $25.0\,\text{cm}^3$ portion (aliquot) of this solution requires $24.00\,\text{cm}^3$ of $0.100\,\text{mol/dm}^3$ hydrochloric acid for complete reaction: $\text{Na}_2\text{CO}_3 + 2\text{HCl} -> 2\text{NaCl} + \text{H}_2\text{O} + \text{CO}_2$. Calculate the percentage purity of the sample ($M_r(\text{Na}_2\text{CO}_3) = 106$).

Step 1 — moles HCl used in the aliquot: $n(\text{HCl}) = 0.100 \times \frac{24.00}{1000} = 0.002400$ mol.

Step 2 — moles Na_2CO_3 in the aliquot (ratio Na_2CO_3 : HCl $= 1:2$): $n = \frac{0.002400}{2} = 0.001200$ mol.

Step 3 — scale up to the whole $250\,\text{cm}^3$ (the aliquot is $25.0/250 = 1/10$ of the total):

$$n(\text{Na}_2\text{CO}_3)_{\text{total}} = 0.001200 \times 10 = 0.01200 \text{ mol}.$$

Step 4 — mass of pure Na_2CO_3: $m = 0.01200 \times 106 = 1.272$ g.

Step 5 — percentage purity: $\%\,\text{purity} = \frac{1.272}{1.325} \times 100 = 96.0\%$.

Ví dụ mẫu · Volume of acid needed for a known mass of oxide

Calculate the volume of $0.500\,\text{mol/dm}^3$ hydrochloric acid needed to exactly react with $2.00\,\text{g}$ of magnesium oxide, MgO ($M_r = 40$): $\text{MgO} + 2\text{HCl} -> \text{MgCl}_2 + \text{H}_2\text{O}$.

$$n(\text{MgO}) = \frac{2.00}{40} = 0.0500 \text{ mol}.$$

Mole ratio MgO : HCl $= 1:2$, so $n(\text{HCl}) = 2 \times 0.0500 = 0.100$ mol.

$$V(\text{HCl}) = \frac{0.100}{0.500} = 0.200 \text{ dm}^3 = 200 \text{ cm}^3.$$

7.8 Practice

Bài tập luyện tập

A solution has pH 2. Which ion is present in far greater concentration than in pure water?

(A) OH^-
(B) H^+
(C) Na^+
(D) Cl^-

Lời giải chi tiết

A pH well below 7 indicates a high concentration of H^+ ions relative to OH^-. **(B)**.

Bài tập luyện tập

Predict the colour of (a) litmus paper and (b) phenolphthalein solution when added to dilute sulfuric acid, and then to sodium hydroxide solution.

Lời giải chi tiết

In dilute H_2SO_4 (acidic): litmus is/turns **red**; phenolphthalein remains **colourless**. In NaOH solution (alkaline): litmus is/turns **blue**; phenolphthalein turns **pink**.

Bài tập luyện tập

Give one example each of (a) an acid, (b) a base that is not an alkali, and (c) an alkali, stating the ion each is associated with.

Lời giải chi tiết

(a) Hydrochloric acid, HCl — associated with H^+. (b) Copper(II) oxide, CuO — a base (neutralises acids) but insoluble, so no free OH^- in solution. (c) Sodium hydroxide, NaOH — a soluble base (alkali), associated with OH^-.

Bài tập luyện tập

Universal indicator turns green when added to a solution. What is the approximate pH, and what does this indicate about the solution?

(A) pH 1 — strongly acidic
(B) pH 5 — weakly acidic
(C) pH 7 — neutral
(D) pH 12 — strongly alkaline

Lời giải chi tiết

Green corresponds to **pH 7**, i.e. a **neutral** solution. **(C)**.

Bài tập luyện tập

(Supplement) Equal volumes of $1.0\,\text{mol/dm}^3$ HCl and $1.0\,\text{mol/dm}^3$ CH_3COOH are compared. Which statement is correct?

(A) Both have the same pH since their concentrations are equal

(B) HCl has the lower pH because it ionises more fully

(C) CH_3COOH has the lower pH because it is a stronger acid

(D) Both conduct electricity equally well

Lời giải chi tiết

HCl is a strong acid and ionises completely, giving a much higher concentration of free H^+ than the weak, partially-ionised CH_3COOH at the same nominal concentration — so HCl has the **lower pH**. **(B)**.

Bài tập luyện tập

(Supplement) Distinguish between the terms "strong/weak" and "concentrated/dilute" as applied to acids.

Lời giải chi tiết

Strong/weak refers to the *degree of ionisation* of the acid in water — a fixed property of that acid (strong acids ionise completely, weak acids only partially). **Concentrated/dilute** refers to the *amount of acid dissolved per* dm^3 *of solution* — this can be changed simply by adding water, and is unrelated to how completely the acid ionises.

Bài tập luyện tập

(Supplement) A $0.10\,\text{mol/dm}^3$ weak acid has pH 4. What would its pH be if it were fully ionised at the same concentration?

(A) 1

(B) 4

(C) 7

(D) 10

Lời giải chi tiết

Full ionisation of $0.10\,\text{mol/dm}^3$ acid gives $[H^+] = 0.10 = 10^{-1}\ \text{mol/dm}^3$, so pH $= 1$. **(A)**.

Bài tập luyện tập

Which gas is produced when a reactive metal reacts with a dilute acid, and how is it identified?

(A) Oxygen; relights a glowing splint

(B) Carbon dioxide; turns limewater milky

(C) Hydrogen; a lighted splint gives a squeaky pop

(D) Chlorine; bleaches damp litmus paper

Lời giải chi tiết

Metal + acid → salt + **hydrogen**, identified by the squeaky pop test with a lighted splint. **(C)**.

Bài tập luyện tập

Write balanced symbol equations for: (a) zinc with dilute sulfuric acid; (b) copper(II) oxide with dilute hydrochloric acid; (c) calcium carbonate with dilute nitric acid.

Lời giải chi tiết

(a) $Zn + H_2SO_4 -> ZnSO_4 + H_2$.
(b) $CuO + 2HCl -> CuCl_2 + H_2O$.
(c) $CaCO_3 + 2HNO_3 -> Ca(NO_3)_2 + H_2O + CO_2$.

Bài tập luyện tập

What would you observe when magnesium ribbon is added to dilute hydrochloric acid?

(A) A blue precipitate forms
(B) Effervescence, the metal dissolves, and the mixture warms up
(C) The solution turns milky
(D) No visible change

Lời giải chi tiết

Bubbles of hydrogen gas form (effervescence), the metal gradually dissolves, and the reaction is exothermic (mixture warms up). **(B)**.

Bài tập luyện tập

Which pair consists of one acidic oxide and one basic oxide?

(A) CO_2 and MgO
(B) Al_2O_3 and ZnO
(C) SO_2 and CO_2
(D) Na_2O and CaO

Lời giải chi tiết

CO_2 (non-metal, acidic) and MgO (metal, basic) — exactly one of each. **(A)**.

Bài tập luyện tập

(Supplement) Name a neutral oxide and describe how it behaves with acids and alkalis.

Lời giải chi tiết

Carbon monoxide, CO (or nitrogen monoxide, NO) — a **neutral** oxide that reacts with neither acids nor alkalis and does not affect pH.

Bài tập luyện tập

Which oxide reacts with sodium hydroxide solution but not with dilute hydrochloric acid?

(A) MgO
(B) SO_2
(C) Al_2O_3
(D) CO

Lời giải chi tiết

SO_2 is a non-metal (**acidic**) oxide: it reacts with alkalis but not acids. MgO is basic (acids only); Al_2O_3 is amphoteric (both); CO is neutral (neither). **(B)**.

Bài tập luyện tập

Sulfur trioxide gas is bubbled into sodium hydroxide solution. What type of oxide is SO_3, and what salt is formed?

(A) Basic; Na_2SO_3
(B) Acidic; Na_2SO_4
(C) Amphoteric; $NaHSO_4$
(D) Neutral; no reaction

Lời giải chi tiết

SO_3 is acidic: $SO_3 + 2NaOH -> Na_2SO_4 + H_2O$, giving sodium **sulfate**. **(B)**.

Bài tập luyện tập

Outline the steps to prepare a pure, dry sample of zinc sulfate crystals from zinc oxide and dilute sulfuric acid.

Lời giải chi tiết

Excess method (since ZnO is an insoluble base): warm the dilute H_2SO_4; add ZnO powder a little at a time until in slight excess ($ZnO + H_2SO_4 -> ZnSO_4 + H_2O$); **filter** off unreacted ZnO; evaporate the filtrate to a saturated solution; leave to cool and crystallise; **filter**, wash with a little cold distilled water, and dry between filter paper.

Bài tập luyện tập

Which method is used to prepare potassium chloride from potassium hydroxide and hydrochloric acid, both of which are soluble?

(A) Excess solid method
(B) Titration, then repeat without indicator and crystallise
(C) Precipitation
(D) Direct heating of the two solids together

Lời giải chi tiết

Since both reactants are soluble, there is no solid excess to filter off; the exact reacting volumes must be found by **titration**. **(B)**.

Bài tập luyện tập

Lead(II) sulfate is insoluble in water. Which method should be used to prepare a pure, dry sample of it?

(A) Titration of lead(II) oxide with sulfuric acid
(B) Mixing lead(II) nitrate solution and sodium sulfate solution, then filtering
(C) Evaporating a solution of lead(II) sulfate to dryness
(D) Adding excess lead metal to dilute sulfuric acid

Lời giải chi tiết

An insoluble salt is made by **precipitation**: mix two soluble solutions whose ions combine to form the insoluble salt, then filter, wash and dry. **(B)**.

Bài tập luyện tập

Which pair of solutions would produce a precipitate when mixed?

(A) $NaNO_3$ and KCl
(B) $AgNO_3$ and NaCl
(C) NaCl and KNO_3
(D) Na_2SO_4 and KCl

Lời giải chi tiết

$AgNO_3 + NaCl -> AgCl\downarrow + NaNO_3$: AgCl is insoluble, so a white precipitate forms; every possible product in the other options is soluble. **(B)**.

Bài tập luyện tập

(Supplement) Write the full equation and the ionic equation for the precipitation of barium sulfate from barium chloride solution and sodium sulfate solution, and state its colour.

Lời giải chi tiết

Full: $BaCl_2(aq) + Na_2SO_4(aq) -> BaSO_4(s) + 2NaCl(aq)$.
Ionic (spectator ions Na^+, Cl^- omitted): $Ba^{2+}(aq) + SO_4^{2-}(aq) -> BaSO_4(s)$ — a **white** precipitate.

Bài tập luyện tập

A colourless solution gives no effervescence with dilute hydrochloric acid. A separate portion is acidified with dilute nitric acid and then silver nitrate solution is added, producing a white precipitate. Which ion is present, and what is the precipitate?

(A) CO_3^{2-}; $BaCO_3$
(B) SO_4^{2-}; $BaSO_4$
(C) Cl^-; AgCl
(D) NO_3^-; $AgNO_3$

Lời giải chi tiết

No effervescence with acid rules out carbonate. A white precipitate with acidified silver nitrate is the standard test for **chloride** ions, giving **silver chloride**. **(C)**.

Bài tập luyện tập

(Supplement) Describe an experiment (other than measuring pH directly) that would show hydrochloric acid is a stronger acid than ethanoic acid at the same concentration.

Lời giải chi tiết

Add equal-sized pieces of magnesium ribbon to equal volumes of each acid at the same concentration and collect the gas produced in a gas syringe, recording the volume collected in a fixed time (or timing how long the ribbon takes to disappear). The hydrochloric acid produces

gas faster (or the magnesium disappears sooner), showing it supplies a higher concentration of free H^+ ions and so is the stronger acid.

Bài tập luyện tập

Which oxide is amphoteric and reacts with *both* dilute hydrochloric acid and sodium hydroxide solution?

(A) Al_2O_3
(B) CuO
(C) CO_2
(D) Na_2O

Lời giải chi tiết

Al_2O_3 is **amphoteric**: it reacts with acids (as a base) and with alkalis (as an acid). **(A)**.

Bài tập luyện tập

$25.0\,\text{cm}^3$ of $0.120\,\text{mol/dm}^3$ sodium hydroxide is titrated against dilute hydrochloric acid. A rough titration required approximately $21\,\text{cm}^3$. Three accurate titres are recorded: $20.85\,\text{cm}^3$, $20.75\,\text{cm}^3$, $20.80\,\text{cm}^3$. Explain which titres should be averaged, and calculate the mean.

Lời giải chi tiết

The rough titration is discarded (it is only a guide). The three accurate titres span $20.85 - 20.75 = 0.10\,\text{cm}^3$, within the usual $0.10\,\text{cm}^3$ concordance limit, so all three are **concordant** and are averaged: mean $= \dfrac{20.85 + 20.75 + 20.80}{3} = 20.80\,\text{cm}^3$.

Bài tập luyện tập

Using the mean titre of $20.80\,\text{cm}^3$ found above, calculate the concentration of the hydrochloric acid.

Lời giải chi tiết

$n(\text{NaOH}) = 0.120 \times \dfrac{25.0}{1000} = 0.00300\,\text{mol} = n(\text{HCl})$ (1:1 ratio).
$c(\text{HCl}) = \dfrac{0.00300}{20.80/1000} = 0.144\,\text{mol/dm}^3$ (3 s.f.).

Bài tập luyện tập

What mass of solid copper(II) oxide is needed to exactly react with $50.0\,\text{cm}^3$ of $2.00\,\text{mol/dm}^3$ sulfuric acid, $\text{CuO} + \text{H}_2\text{SO}_4 -> \text{CuSO}_4 + \text{H}_2\text{O}$ ($M_r(\text{CuO}) = 80$)?

Lời giải chi tiết

$n(\text{H}_2\text{SO}_4) = 2.00 \times \dfrac{50.0}{1000} = 0.100\,\text{mol} = n(\text{CuO})$ (1:1 ratio).
$m(\text{CuO}) = 0.100 \times 80 = 8.00\,\text{g}$.

Bài tập luyện tập

$22.5\,\text{cm}^3$ of $0.120\,\text{mol/dm}^3$ sodium hydroxide exactly neutralises $15.0\,\text{cm}^3$ of dilute sulfuric acid. Calculate the concentration of the sulfuric acid.

Lời giải chi tiết

$n(\text{NaOH}) = 0.120 \times \dfrac{22.5}{1000} = 0.00270$ mol. Ratio NaOH : $H_2SO_4 = 2:1$, so $n(H_2SO_4) = 0.00135$ mol.
$c(H_2SO_4) = \dfrac{0.00135}{15.0/1000} = 0.0900$ mol/dm^3.

Bài tập luyện tập

What volume of $0.200\,\text{mol/dm}^3$ sodium hydroxide solution is required to exactly neutralise $30.0\,\text{cm}^3$ of $0.150\,\text{mol/dm}^3$ sulfuric acid?

Lời giải chi tiết

$H_2SO_4 + 2NaOH -> Na_2SO_4 + 2H_2O$: mole ratio $1:2$.
$n(H_2SO_4) = 0.150 \times \dfrac{30.0}{1000} = 0.00450$ mol; $n(\text{NaOH}) = 2 \times 0.00450 = 0.00900$ mol.
$V(\text{NaOH}) = \dfrac{0.00900}{0.200} = 0.0450\ \text{dm}^3 = 45.0\ \text{cm}^3$.

Bài tập luyện tập

$25.0\,\text{cm}^3$ of $0.200\,\text{mol/dm}^3$ hydrochloric acid exactly neutralises $20.0\,\text{cm}^3$ of potassium hydroxide solution. Calculate (a) the concentration of the KOH, and (b) the mass of potassium chloride ($M_r = 74.5$) obtainable by evaporation to dryness.

Lời giải chi tiết

$n(\text{HCl}) = 0.200 \times \dfrac{25.0}{1000} = 0.00500$ mol $= n(\text{KOH}) = n(\text{KCl})$ (1:1 ratio).
(a) $c(\text{KOH}) = \dfrac{0.00500}{20.0/1000} = 0.250$ mol/dm^3.
(b) $m(\text{KCl}) = 0.00500 \times 74.5 = 0.373$ g.

Bài tập luyện tập

$1.0\,\text{mol/dm}^3$ hydrochloric acid is progressively diluted with distilled water. Explain what happens to its pH, and whether it could ever become alkaline by dilution alone.

Lời giải chi tiết

Dilution reduces the concentration of free H^+ ions, so the pH **rises**, moving from strongly acidic towards 7. Dilution with water alone can only bring the pH *towards* neutral — it can never cross into alkaline territory (pH > 7), since dilution neither creates OH^- ions nor removes more H^+ than was originally present.

Bài tập luyện tập

A $1.800\,\text{g}$ sample of impure sodium carbonate is made up to $250\,\text{cm}^3$ of solution; a $25.0\,\text{cm}^3$ aliquot requires $22.50\,\text{cm}^3$ of $0.120\,\text{mol/dm}^3$ HCl for complete reaction ($\text{Na}_2\text{CO}_3 + 2\text{HCl} -> 2\text{NaCl} + \text{H}_2\text{O} + \text{CO}_2$, $M_r(\text{Na}_2\text{CO}_3) = 106$). Calculate the percentage purity of the sample.

Lời giải chi tiết

$n(\text{HCl}) = 0.120 \times \dfrac{22.50}{1000} = 0.002700$ mol; $n(\text{Na}_2\text{CO}_3)_{\text{aliquot}} = \dfrac{0.002700}{2} = 0.001350$ mol.
Scaling by $250/25.0 = 10$: $n(\text{Na}_2\text{CO}_3)_{\text{total}} = 0.01350$ mol; $m = 0.01350 \times 106 = 1.431$ g.
$\%$ purity $= \dfrac{1.431}{1.800} \times 100 = 79.5\%$.

Bài tập luyện tập

Explain why the burette should be rinsed with the titrant solution before use, but the conical flask should be rinsed only with distilled water.

Lời giải chi tiết

If the burette were left wet with water, the titrant delivered from it would be slightly diluted, giving an inflated titre. The conical flask receives an *exact* pipetted volume of analyte — a trace of extra water left inside does not change the *number of moles* of analyte present, but any leftover titrant or analyte solution would add extra, uncounted moles, so it is rinsed with distilled water only.

Bài tập luyện tập

(Supplement) Explain why, when titrating equal concentrations of HCl and H_2SO_4 against the same sodium hydroxide solution, twice the volume of NaOH is needed to neutralise a given volume of H_2SO_4 compared with HCl.

Lời giải chi tiết

Each mole of HCl supplies 1 mol H^+ (1:1 with NaOH); each mole of H_2SO_4 supplies 2 mol H^+ (1:2 with NaOH). At equal concentration and volume, H_2SO_4 therefore needs exactly **twice** the moles — and so twice the volume — of NaOH.

The Periodic Table

Mục tiêu Unit: Cách sắp xếp bảng tuần hoàn theo số hiệu nguyên tử; khái niệm chu kỳ và nhóm; xu hướng biến đổi tính chất trong Chu kỳ 3 (Nâng cao); tính chất và phản ứng của Nhóm I (kim loại kiềm), Nhóm VII (halogen) và Nhóm 0 (khí hiếm); tính chất của nguyên tố chuyển tiếp (Nâng cao) và vai trò xúc tác công nghiệp của chúng.

8.1 Arrangement of the Periodic Table

8.1.1 Periods and groups

The modern Periodic Table lists all known elements in order of increasing **proton (atomic) number**, arranged so that elements with similar chemical properties fall into the same vertical column. Two structural ideas organise the whole table:

Chu kỳ & Nhóm

Period (hàng ngang / horizontal row): all elements in the same period have the *same number of occupied electron shells*. Moving left to right along a period, the proton number increases by one each time, and one more electron is added to the outermost shell.

Group (cột dọc / vertical column): all elements in the same group have the *same number of electrons in their outer shell*, so they show similar chemical behaviour (for the main groups, the group number equals the number of outer-shell electrons — e.g. Group I atoms have 1 outer electron, Group VII atoms have 7).

Metals occupy the left and centre of the table (roughly three-quarters of all elements); **non-metals** occupy the upper right, separated from the metals by a diagonal "staircase" running from boron to astatine. Elements close to this staircase (e.g. silicon) often show intermediate, metalloid-like properties.

VN **GIẢI THÍCH TIẾNG VIỆT**

Bảng tuần hoàn hiện đại sắp xếp các nguyên tố theo **số hiệu nguyên tử (số proton) tăng dần**. **Chu kỳ** (hàng ngang) cho biết **số lớp electron** — cùng chu kỳ thì cùng số lớp. **Nhóm** (cột dọc) cho biết **số electron lớp ngoài cùng** — cùng nhóm thì có tính chất hoá học tương tự nhau vì có cùng số electron hoá trị. Kim loại nằm ở bên trái và giữa bảng; phi kim nằm ở góc trên bên phải, ngăn cách bởi một đường "bậc thang" chéo.

The *length* of each period is fixed by how many electrons the corresponding shells can hold under the simple shell-filling model used at this level (fill $2, 8, 8, \ldots$ from the nucleus outward). Period 1 has only **2** elements (H, He), because the first shell holds a maximum of 2 electrons; Periods 2 and 3 each have **8** elements (Li–Ne, Na–Ar), because the second and third shells each hold up to 8 electrons in this simple model. This is exactly why a new period begins every time a new outer shell starts being filled, and why the table has the striking "steps" in row length that are visible when the transition-element block appears from Period 4 onward.

VN GIẢI THÍCH TIẾNG VIỆT

Độ dài mỗi chu kỳ phụ thuộc vào số electron tối đa mà các lớp electron tương ứng có thể chứa (mô hình đơn giản: lớp lấp đầy theo thứ tự $2, 8, 8, \ldots$). Chu kỳ 1 chỉ có 2 nguyên tố (H, He) vì lớp thứ nhất chứa tối đa 2 electron; Chu kỳ 2 và 3 mỗi chu kỳ có 8 nguyên tố vì lớp thứ hai và thứ ba chứa tối đa 8 electron trong mô hình này.

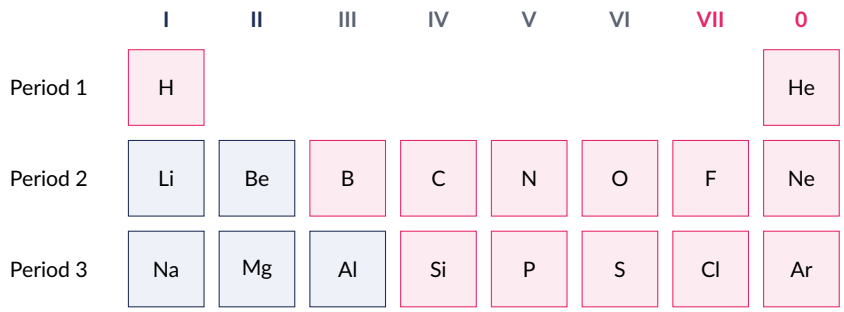


Figure 8.1 — Periods 1–3 sketched against Groups I, II, III, IV, V, VI, VII and 0. Navy cells are metals, pink cells are non-metals. (The transition elements, which fill the centre of the table from Period 4 onward, are not shown here.)

Ví dụ mẫu · Electronic structure → group and period

An atom of magnesium has proton number 12. Write its electronic structure and state its group and period.

Fill the shells $2, 8, 8, \ldots$ from the nucleus outward: $12 = 2 + 8 + 2$, so magnesium's electronic structure is $2, 8, 2$.

Number of shells $= 3 \Rightarrow$ **Period 3**. Outer shell has 2 electrons $\Rightarrow$ **Group II**.

Ví dụ mẫu · Electronic structure → group and period

An atom of chlorine has proton number 17. Write its electronic structure and state its group and period.

$17 = 2 + 8 + 7$, so chlorine's electronic structure is $2, 8, 7$.

Number of shells $= 3 \Rightarrow$ **Period 3**. Outer shell has 7 electrons $\Rightarrow$ **Group VII**.

Ví dụ mẫu · A full outer shell

An atom of neon has proton number 10. Write its electronic structure and state its group and period. Explain why this element is placed in Group 0.

$10 = 2 + 8$, so neon's electronic structure is $2, 8$.

Number of shells $= 2 \Rightarrow$ **Period 2**. The outer shell already holds its maximum of 8 electrons (a **full outer shell**), so no further main-group counting applies in the usual way — elements with a full outer shell are placed in **Group 0**, the noble gases.

VN GIẢI THÍCH TIẾNG VIỆT

Cách làm: lấp đầy các lớp electron theo thứ tự $2, 8, 8, \ldots$ từ trong ra ngoài cho đến khi dùng hết số electron bằng số hiệu nguyên tử. **Số lớp** = số chu kỳ; **số electron lớp ngoài cùng** = số nhóm (đối với các nhóm chính I, II, III, ..., VII, 0).

(!) Lỗi thường gặp: Students often mix up *period* and *group*. Remember: a **period** is a row (reading across gives elements with an *increasing* number of outer electrons but the *same* number of shells); a **group** is a column (reading down gives elements with the *same* number of outer electrons but an *increasing* number of shells). A quick check: sodium (Na) and chlorine (Cl) are in the *same period* (3 shells each) but *different groups* (1 and 7 outer electrons); sodium (Na) and potassium (K) are in the *same group* (1 outer electron each) but *different periods* (3 and 4 shells).

8.1.2 Metals and non-metals: general physical and chemical differences

Besides their position in the table, metals and non-metals differ in a consistent set of general physical and chemical properties that recur throughout this chapter:

Kim loại vs. Phi kim

Metals: shiny (lustrous) when freshly cut/polished; malleable (can be hammered into sheets) and ductile (can be drawn into wires); good conductors of heat and electricity; usually high density and high melting/boiling point (Group I metals are a striking exception — low density, low melting point); make a ringing sound when struck (sonorous); lose electrons in reactions to form **positive ions** (cations); their oxides are typically **basic** (or amphoteric).

Non-metals: dull appearance (solids); brittle when solid (shatter rather than bend); poor conductors of heat and electricity (with the exception of graphite, a form of carbon); generally low density; gain electrons (or share electrons) in reactions to form **negative ions** (anions) or covalent bonds; their oxides are typically **acidic**.

VN **GIẢI THÍCH TIẾNG VIỆT**

Kim loại thường: sáng bóng, dẻo/dễ dát mỏng và kéo sợi, dẫn điện/dẫn nhiệt tốt, khối lượng riêng và nhiệt độ nóng chảy cao (trừ Nhóm I), phát ra tiếng kêu khi gõ, tạo **ion dương** khi phản ứng, ôxit có tính **bazơ**. Phi kim thường: bề mặt xỉn (ở thể rắn), giòn/dễ vỡ, dẫn điện/dẫn nhiệt kém (trừ than chì), khối lượng riêng thấp, tạo **ion âm** hoặc liên kết cộng hoá trị khi phản ứng, ôxit có tính **axit**.

Bài tập luyện tập

A solid element is dull, brittle, a poor conductor of electricity, and forms an acidic oxide. Is this element more likely to be a metal or a non-metal? Justify your answer with two pieces of evidence.

Lời giải chi tiết

It is more likely to be a **non-metal**. Metals are typically shiny and malleable and are good conductors of electricity, whereas this element is dull, brittle and a poor conductor — all typical non-metal properties. In addition, non-metal oxides are typically acidic, matching the given oxide, whereas metal oxides are typically basic (or amphoteric).

8.1.3 Mendeleev's early periodic table (Supplement)

(Supplement) Long before protons or electrons were known, the Russian chemist **Dmitri Mendeleev** published a periodic table in 1869. He arranged the roughly 63 elements known at the time in order of increasing **relative atomic mass** and noticed that their properties recurred periodically. Where the next element in strict mass order did not fit the pattern, Mendeleev boldly left a **gap**, confident

that an undiscovered element belonged there — and used the surrounding pattern to **predict its properties** (density, melting point, likely compounds) in advance.

(Supplement) Mendeleev's predicted "eka-aluminium" and "eka-silicon" were later discovered and named **gallium** (1875) and **germanium** (1886); their real properties matched his predictions remarkably closely. This predictive success was strong early evidence that the periodic pattern reflected something fundamental about atomic structure (we now know it is the repeating pattern of outer-shell electrons).

VN **GIẢI THÍCH TIẾNG VIỆT**

Mendeleev xếp các nguyên tố theo **khối lượng nguyên tử tương đối tăng dần** (lúc đó chưa biết proton/electron). Khi thấy một nguyên tố không khớp quy luật, ông để trống ô đó và **dự đoán tính chất** của nguyên tố còn thiếu — dự đoán sau này khớp gần như hoàn hảo với gali và germani được tìm ra sau đó, chứng tỏ quy luật tuần hoàn phản ánh một cấu trúc sâu xa của nguyên tử (số electron lớp ngoài cùng lặp lại theo chu kỳ).

Ví dụ mẫu · Mendeleev's prediction (Supplement)

(Supplement) Mendeleev left a gap below silicon for an undiscovered element he called "eka-silicon," and predicted it would be a grey metal-like solid with a density around $5.5\,\text{g/cm}^3$ and would form an oxide of formula XO_2. Explain why this was a reasonable prediction, and name the element eventually discovered in this gap.

Because elements in the same group (below silicon) share the same number of outer-shell electrons, "eka-silicon" should behave chemically like silicon: silicon forms SiO_2, so the new element should form an analogous oxide XO_2, and its physical properties should lie between those of its neighbours in the table. The element discovered in this position was **germanium**, Ge, which indeed forms GeO_2 and has a density close to Mendeleev's prediction.

Bài tập luyện tập

What determines which *period* an element is placed in?

(A) Its relative atomic mass

(B) The number of occupied electron shells in its atoms

(C) The number of electrons in its outer shell

(D) Whether it is a metal or non-metal

Lời giải chi tiết

The period number equals the number of electron shells occupied by the atom's electrons. **(B)**.

Bài tập luyện tập

An atom of aluminium has proton number 13. State its electronic structure, and identify its group and period.

Lời giải chi tiết

$13 = 2 + 8 + 3$, so the electronic structure is $2, 8, 3$. Three shells $\Rightarrow$ Period 3; 3 outer electrons $\Rightarrow$ Group III.

Bài tập luyện tập

(Supplement) Explain why Mendeleev is remembered as a key figure in the history of chemistry, even though his original table was based on atomic *mass* rather than atomic (proton) number, which is used today.

Lời giải chi tiết

Mendeleev correctly identified that chemical properties repeat periodically, and used this pattern to leave gaps and predict the properties of undiscovered elements (e.g. gallium, germanium) with striking accuracy — this predictive power showed the periodic law was a genuine pattern of nature, not a coincidence. A few elements only fit the pattern correctly when later re-ordered by proton (atomic) number rather than mass (e.g. tellurium and iodine), which is why the modern table uses proton number, but Mendeleev's fundamental insight — periodicity of properties — remains the basis of the table used today.

Bài tập luyện tập

Sodium and potassium are both soft, low-density metals that react vigorously with water. Are they in the same period or the same group? Explain.

Lời giải chi tiết

Same **group** (Group I). Both have 1 electron in their outer shell, giving them similar chemical behaviour, but sodium has 3 shells (Period 3) while potassium has 4 shells (Period 4) — so they are in different periods.

Bài tập luyện tập

An atom of calcium has proton number 20. Write its electronic structure and state its group and period.

Lời giải chi tiết

$20 = 2 + 8 + 8 + 2$, so the electronic structure is $2, 8, 8, 2$. Four shells $\Rightarrow$ **Period 4**. Outer shell has 2 electrons $\Rightarrow$ **Group II**.

Bài tập luyện tập

Explain why Period 2 contains exactly 8 elements (Li to Ne), using the simple electron-shell filling model.

Lời giải chi tiết

Period 2 elements have their outer electrons in the second shell. Under the simple shell-filling model used at this level, the second shell holds a maximum of 8 electrons, so there are exactly 8 possible outer-electron arrangements (1 through 8 electrons in that shell) before the shell is full and a new period (with a third shell) must begin — giving the 8 elements Li, Be, B, C, N, O, F, Ne.

8.2 Trends across Period 3 (Supplement)

(Supplement) Period 3 (sodium to argon) is the clearest example in the whole table of how properties change steadily as proton number increases across a row.

8.2.1 Metallic to non-metallic character

(Supplement) Moving left to right across Period 3, the elements change gradually from metallic to non-metallic:

Chu kỳ 3 (Supplement)

Na, Mg, Al are metals: shiny, malleable, good conductors of heat and electricity, held together by metallic bonding (a lattice of positive ions in a "sea" of delocalised electrons). Si is a **metalloid**: a giant covalent (macromolecular) structure with some properties intermediate between metals and non-metals (it is a semiconductor). P, S, Cl, Ar are non-metals, existing as simple molecules (P_4, S_8, Cl_2) or, for argon, single atoms — poor conductors, often gases or low-melting solids/liquids.

VN **GIẢI THÍCH TIẾNG VIỆT**

(Supplement) Đi từ trái sang phải trong Chu kỳ 3: Na, Mg, Al là kim loại (liên kết kim loại, dẫn điện tốt); Si là á kim (cấu trúc cộng hoá trị khổng lồ, bán dẫn); P, S, Cl, Ar là phi kim (tồn tại dạng phân tử đơn giản hoặc nguyên tử đơn lẻ). Vậy **tính kim loại giảm dần**, **tính phi kim tăng dần** khi đi từ trái sang phải trong một chu kỳ.

8.2.2 Acid-base nature of Period 3 oxides

(Supplement) Each Period 3 element forms an oxide with oxygen; the acid-base character of these oxides changes from strongly **basic** on the left to strongly **acidic** on the right, with an **amphoteric** oxide in between:

Oxide	Bonding/structure	Acid–base nature	Reaction summary
Na_2O	ionic	basic	dissolves in water: forms NaOH (alkaline solution)
MgO	ionic	basic	reacts with acids to form a salt + water
Al_2O_3	ionic/covalent character	**amphoteric**	reacts with both acids *and* alkalis
SiO_2	giant covalent	weakly acidic	insoluble in water; reacts with hot conc. NaOH
P_4O_{10}	simple molecular	acidic	reacts with water: forms H_3PO_4
SO_3	simple molecular	acidic	reacts with water: forms H_2SO_4

Table 8.1 — Acid–base trend of Period 3 oxides (Supplement). Basic oxides dominate on the metal side; acidic oxides dominate on the non-metal side.

Định nghĩa (Supplement)

An **amphoteric** oxide reacts with *both* acids and alkalis. Al_2O_3 behaves as a base with acids, $Al_2O_3 + 6HCl -> 2AlCl_3 + 3H_2O$, and as an acid with concentrated alkali, $Al_2O_3 + 2NaOH -> 2NaAlO_2 + H_2O$.

VN **GIẢI THÍCH TIẾNG VIỆT**

(Supplement) Ôxit **lưỡng tính** phản ứng được với *cả* axit lẫn bazơ mạnh — ví dụ Al_2O_3. Xu hướng chung trong Chu kỳ 3: ôxit của kim loại (bên trái) có tính **bazơ**; ôxit của phi kim (bên phải) có tính **axit**; ở giữa, ôxit nhôm mang tính **lưỡng tính** — phản ánh đúng xu hướng tính kim loại giảm dần, tính phi kim tăng dần.

Ví dụ mẫu · Classifying Period 3 oxides (Supplement)

(Supplement) Classify Na_2O, Al_2O_3 and SO_3 as basic, amphoteric or acidic, and write one equation for each showing how it reacts with an acid or an alkali (as appropriate).
Na_2O — **basic**: reacts with acid to form a salt and water, $Na_2O + 2HCl -> 2NaCl + H_2O$.
Al_2O_3 — **amphoteric**: reacts with acid, $Al_2O_3 + 6HCl -> 2AlCl_3 + 3H_2O$, *and* with alkali, $Al_2O_3 + 2NaOH -> 2NaAlO_2 + H_2O$.
SO_3 — **acidic**: reacts with alkali to form a salt and water, $SO_3 + 2NaOH -> Na_2SO_4 + H_2O$ (it also reacts directly with water to form sulfuric acid, $SO_3 + H_2O -> H_2SO_4$).

Bài tập luyện tập

(Supplement) Which Period 3 oxide reacts with both dilute hydrochloric acid and sodium hydroxide solution?

(A) Na_2O
(B) MgO
(C) Al_2O_3
(D) SO_3

Lời giải chi tiết

Al_2O_3 is amphoteric, so it reacts with both acids and alkalis. **(C)**.

Bài tập luyện tập

(Supplement) State whether P_4O_{10} is basic or acidic, and write an equation for its reaction with water.

Lời giải chi tiết

P_4O_{10} is **acidic** (a non-metal oxide). $P_4O_{10} + 6H_2O -> 4H_3PO_4$ (phosphoric acid).

Bài tập luyện tập

(Supplement) Describe the trend in metallic character across Period 3 from sodium to argon, and name the one element that behaves as a metalloid.

Lời giải chi tiết

Metallic character **decreases** (non-metallic character increases) across the period from sodium to argon. **Silicon** is the metalloid, showing intermediate/semiconducting properties between the metals (Na, Mg, Al) and the non-metals (P, S, Cl, Ar).

Bài tập luyện tập

(Supplement) MgO is added separately to (i) dilute hydrochloric acid and (ii) sodium hydroxide solution. Predict what happens in each case, and explain in terms of its acid-base character.

Lời giải chi tiết

MgO is a **basic** oxide (typical of the metals on the left of Period 3), not amphoteric. (i) It reacts with the acid: $MgO + 2HCl -> MgCl_2 + H_2O$. (ii) It does *not* react with sodium hydroxide

solution, since a basic oxide reacts only with acids, not with alkalis.

Bài tập luyện tập

(Supplement) SiO_2 (silicon dioxide, e.g. the main component of sand) does not dissolve in water. Explain this in terms of its structure, and state whether SiO_2 is basic or acidic.

Lời giải chi tiết

SiO_2 is a **giant covalent (macromolecular)** structure: every silicon atom is bonded to four oxygen atoms by strong covalent bonds throughout the whole solid, so an enormous amount of energy would be needed to break it apart — it does not simply dissolve as separate molecules the way a simple molecular oxide might. SiO_2 is **acidic** (though only weakly reactive because of this very stable structure); it will react with hot, concentrated sodium hydroxide.

8.3 Group I: the alkali metals

8.3.1 Physical properties

Lithium, sodium and potassium are the first three members of **Group I**, the **alkali metals**. All have just **one electron in their outer shell**. They are unusual metals: soft enough to cut with a knife (revealing a shiny surface that tarnishes within seconds as it reacts with oxygen and moisture in the air), and all three have a density low enough to **float on water**.

Metal	Density (g/cm^3)	Melting point (°C)	Flame colour when burnt
Lithium (Li)	0.53	181	crimson red
Sodium (Na)	0.97	98	yellow-orange
Potassium (K)	0.86	63	lilac

Table 8.2 — Selected physical properties of Li, Na, K. All three are less dense than water ($1.00\,\mathrm{g/cm^3}$); melting point decreases steadily down the group.

VN **GIẢI THÍCH TIẾNG VIỆT**

Nhóm I (kim loại kiềm: Li, Na, K, ...) có **1 electron lớp ngoài cùng**. Chúng là kim loại mềm (cắt được bằng dao), có **khối lượng riêng thấp** (Li, Na, K đều nổi trên nước) và bề mặt sáng bóng nhanh chóng xỉn màu trong không khí do phản ứng với ôxy/hơi ẩm. Vì phản ứng rất mạnh, các kim loại kiềm hoạt động nhất (K trở lên) thường được bảo quản ngập trong dầu hoả.

8.3.2 Reactions with water, oxygen and chlorine

All Group I metals react readily with water, oxygen and chlorine, always forming compounds where the metal has a $+1$ charge.

Phản ứng đặc trưng của Nhóm I

With water: $2M + 2H_2O -> 2MOH + H_2$ — the metal floats, moves/fizzes across the surface as hydrogen gas is released, and may melt into a ball from the heat of reaction; the resulting solution turns universal indicator/litmus **blue/purple** (alkaline, from the soluble metal hydroxide MOH). Lithium reacts steadily; sodium reacts vigorously, often melting into a molten ball; potassium reacts violently, usually igniting the released hydrogen with a lilac-tinged flame and sometimes popping/spitting.

With oxygen: $4M + O_2 -> 2M_2O$ — forms a white/grey metal oxide, which is why the freshly-

cut shiny surface of a Group I metal tarnishes (dulls) within seconds in air.

With chlorine: $2M + Cl_2 -> 2MCl$ — the metal burns in chlorine gas to form a white, ionic metal chloride (e.g. common salt, NaCl).

VN **GIẢI THÍCH TIẾNG VIỆT**

Kim loại kiềm phản ứng với **nước** tạo hydroxit kiềm tan (dung dịch làm quỳ tím/chỉ thị hoá xanh) và khí hydro; phản ứng với **ôxy** tạo ôxit kim loại (làm bề mặt kim loại xỉn màu); phản ứng với **clo** tạo muối clorua trắng. Mức độ phản ứng mãnh liệt tăng dần từ Li → Na → K.

Because Group I metals react so readily with the oxygen and water vapour naturally present in air, samples of sodium and potassium are normally **stored under oil** in the laboratory (lithium is less reactive but is often stored the same way as a precaution). This physically excludes air and moisture from the metal surface, preventing the slow tarnishing reaction (and, for the more reactive metals, removing any fire risk) between storage uses.

8.3.3 Trend in reactivity down the group

Reactivity increases down Group I (Li < Na < K). This is explained entirely by atomic structure:

Going down the group, each successive metal has **one more occupied electron shell**. This means: (1) the outer electron is **further from the nucleus**, and (2) it is **shielded** by more inner shells of electrons. Both effects **weaken the electrostatic attraction** between the positive nucleus and the single outer electron, so that outer electron is **lost more easily** to form an M^+ ion — reactivity depends on how easily the atom loses its outer electron, so reactivity **increases** down the group.

VN **GIẢI THÍCH TIẾNG VIỆT**

Xuống dưới nhóm, nguyên tử có thêm lớp electron → electron lớp ngoài cùng **xa hạt nhân hơn** và bị **chắn nhiều hơn** bởi các lớp electron bên trong → lực hút hạt nhân lên electron này **yếu đi** → electron dễ bị mất hơn → kim loại **hoạt động mạnh hơn**. Đây là lý do K phản ứng với nước mãnh liệt hơn Na, và Na mãnh liệt hơn Li.

8.3.4 Trend in melting point down the group

Unlike reactivity, **melting point decreases down Group I** (Li > Na > K, Table 8.2). In a Group I metal, the metallic bond is the electrostatic attraction between the lattice of positive metal ions and the "sea" of delocalised outer electrons. Down the group, the metal ions become **larger** and hold only **one** delocalised electron each, so the metallic bond becomes progressively **weaker** (the delocalised electrons are, on average, further from the positive ions) — less energy is needed to break the lattice apart, so the melting point falls.

Ví dụ mẫu · Reactivity trend: Li, Na, K

Rank lithium, sodium and potassium in order of increasing reactivity with water, and explain the trend in terms of atomic structure.

Order: Li < Na < K.

Li $(2, 1)$, Na $(2, 8, 1)$ and K $(2, 8, 8, 1)$ each have **one** outer electron, but the number of electron shells increases from Li (2 shells) to Na (3 shells) to K (4 shells). As the number of shells increases, the outer electron is further from the nucleus and shielded by more inner-shell electrons, so the nuclear attraction holding it in place is weaker. The outer electron is therefore lost more easily going down the group — so potassium reacts most vigorously with water (vi-

olently, often igniting), sodium reacts vigorously (melts into a ball, fizzes rapidly), and lithium reacts the least vigorously of the three (steady fizzing, no melting).

(!) Lỗi thường gặp: It looks contradictory that reactivity **increases** down Group I but **decreases** down Group VII (covered later in this chapter) — but both trends have the *same underlying cause*: increasing atomic radius and shielding down a group. In Group I, atoms react by **losing** their single outer electron, and this is *easier* the further that electron is from the nucleus — so reactivity increases. In Group VII, atoms react by **gaining** one more electron into the outer shell, and this is *harder* the further the outer shell is from the nucleus (the incoming electron is attracted less strongly, and screened more by inner shells) — so reactivity decreases. Always ask: "does this group react by losing or gaining an electron?" before predicting the direction of the trend.

Bài tập luyện tập

Which observation would you expect when a small piece of potassium is added to water?

(A) It sinks and dissolves slowly with no visible reaction

(B) It floats, fizzes gently, and the solution stays colourless and neutral

(C) It floats, moves rapidly, and typically ignites with a lilac flame

(D) It reacts only when the water is heated to boiling

Lời giải chi tiết

Potassium is highly reactive; it floats (low density), reacts violently and typically ignites the hydrogen produced, burning with a lilac flame. **(C)**.

Bài tập luyện tập

Write a balanced equation for the reaction of lithium with water, and state the pH range of the resulting solution.

Lời giải chi tiết

$2Li + 2H_2O -> 2LiOH + H_2$. The solution contains dissolved lithium hydroxide, an alkali, so it has pH > 7 (typically around pH 12–13).

Bài tập luyện tập

Explain why a freshly cut piece of sodium is shiny but quickly becomes dull grey when left in air.

Lời giải chi tiết

Freshly cut sodium exposes shiny, unreacted metal. It reacts rapidly with oxygen (and moisture) in the air, $4Na + O_2 -> 2Na_2O$, forming a dull layer of sodium oxide on the surface.

Bài tập luyện tập

Which of the following correctly ranks lithium, sodium and potassium in order of *decreasing* melting point?

(A) K > Na > Li
(B) Li > Na > K
(C) Na > K > Li
(D) All three have the same melting point

Lời giải chi tiết

Melting point decreases down Group I as the metallic bond weakens (larger ions, same single delocalised electron each), so Li > Na > K. **(B)**.

Bài tập luyện tập

A student burns a small sample of sodium in a gas jar of chlorine. Describe what is observed and write the equation for the reaction.

Lời giải chi tiết

The sodium burns with a bright orange-yellow flame, producing dense white fumes/solid of sodium chloride that settle inside the gas jar. $2Na + Cl_2 -- > 2NaCl$.

Bài tập luyện tập

Explain why samples of sodium and potassium are normally stored under oil in the laboratory.

Lời giải chi tiết

Sodium and potassium react readily with the oxygen and water vapour naturally present in air. Storing them under oil physically excludes air and moisture from the metal surface, preventing this reaction (tarnishing, and for the more reactive metals, reducing fire risk) between uses.

Bài tập luyện tập

A piece of potassium and a piece of lithium of similar size are each dropped into separate beakers of cold water. State *two* observable differences between the two reactions, and explain them.

Lời giải chi tiết

Potassium reacts far more violently than lithium: (1) potassium moves rapidly across the surface and typically ignites the hydrogen gas produced, burning with a lilac flame, while lithium simply fizzes steadily without igniting; (2) potassium may spit or cause a small explosion, while lithium's reaction is calm and controlled. This is because potassium's outer electron (4 shells) is further from the nucleus and more shielded than lithium's (2 shells), so it is lost more easily — making potassium more reactive.

8.4 Group VII: the halogens

8.4.1 Physical properties down the group

The halogens — fluorine, chlorine, bromine, iodine — are non-metals that exist as **diatomic molecules** (F_2, Cl_2, Br_2, I_2), each atom having **seven electrons** in its outer shell.

Halogen	Formula	State/colour at RTP	Notes
Fluorine	F_2	pale yellow gas	extremely reactive/dangerous — not tested in school
Chlorine	Cl_2	(yellow-)green gas	toxic; denser than air
Bromine	Br_2	red-brown liquid	volatile; gives dense orange-brown/red-brown vapour
Iodine	I_2	grey-black solid	sublimes on heating to a purple vapour

Table 8.3 — Physical states and colours of the first four halogens at room temperature and pressure.

VN **GIẢI THÍCH TIẾNG VIỆT**

Nhóm VII (halogen: F, Cl, Br, I) là phi kim, tồn tại dạng phân tử 2 nguyên tử, có **7 electron lớp ngoài cùng**. Trạng thái/màu sắc ở nhiệt độ phòng: F_2 khí vàng nhạt (quá nguy hiểm, không thử ở trường học), Cl_2 khí (vàng-)lục, Br_2 chất lỏng nâu đỏ (bốc hơi tạo khí màu nâu cam), I_2 chất rắn đen xám (thăng hoa tạo hơi tím khi đun nóng).

Notice that the state of each halogen at room temperature (gas → gas → liquid → solid, going down the group) follows directly from a steadily **rising melting and boiling point**. Halogen molecules are simple, non-polar molecules held to their neighbours only by weak **van der Waals forces**. Going down the group, each molecule has more electrons and a larger electron cloud, so these van der Waals forces become stronger — more energy is needed to separate the molecules, so melting and boiling points rise steadily from fluorine to iodine.

8.4.2 Trend in reactivity down the group

Reactivity decreases down Group VII ($F_2 > Cl_2 > Br_2 > I_2$) — the opposite direction to Group I, but explained by the same idea of atomic radius and shielding.

Halogen atoms react by **gaining one electron** into their outer shell to complete it (forming a -1 ion, or a shared pair in a covalent bond). Going down the group, atoms have **more shells**, so the outer shell is **further from the nucleus** and more **shielded** by inner electrons — the incoming electron is attracted less strongly, so it is harder to gain. Reactivity therefore **decreases** down the group.

VN **GIẢI THÍCH TIẾNG VIỆT**

Nguyên tử halogen phản ứng bằng cách **nhận thêm 1 electron** để lấp đầy lớp ngoài cùng. Xuống dưới nhóm, lớp ngoài cùng **xa hạt nhân hơn** và bị **chắn nhiều hơn** → khó hút electron mới vào hơn → tính hoạt động hoá học **giảm dần** xuống dưới nhóm (ngược chiều so với Nhóm I).

Ví dụ mẫu · Extrapolating the trend

Astatine, At, lies directly below iodine in Group VII. Predict (i) its physical state and colour at room temperature, and (ii) whether it is more or less reactive than iodine, giving reasons based on the trends established for the other halogens.

(i) Melting and boiling points rise steadily down Group VII as the molecules get larger and van der Waals forces strengthen; iodine is already a solid, so astatine, being lower still, is predicted to be a **solid** at room temperature, likely dark-coloured (continuing the trend from pale yellow gas to grey-black solid).

(ii) Reactivity decreases down the group (larger, more shielded outer shell ⇒ harder to attract one more electron), so astatine is predicted to be **less reactive** than iodine.

Bài tập luyện tập

Explain, in terms of intermolecular forces, why iodine has a much higher melting point than chlorine.

Lời giải chi tiết

Both are simple molecular substances held together (between molecules) only by weak van der Waals forces. Iodine molecules (I_2) are larger and have more electrons than chlorine molecules (Cl_2), so the van der Waals forces between iodine molecules are stronger. More energy is therefore needed to overcome these forces and melt iodine, giving it a much higher melting point than chlorine.

Figure 8.2 — Opposite reactivity trends: the wedge widens going down Group I (reactivity increases: outer electron is lost more easily) and narrows going down Group VII (reactivity decreases: it is harder to attract one more electron).

8.4.3 Displacement reactions

A more reactive halogen will **displace** a less reactive halogen from an aqueous solution of its salt (a halide), because the more reactive halogen atoms are better at gaining an electron and so oxidise the halide ions already in solution.

Quy tắc thế halogen

General pattern: $X_2 + 2NaY -> 2NaX + Y_2$, where X_2 is a *more reactive* halogen than Y_2 (i.e. X lies *above* Y in Group VII). A displacement reaction is usually visible as a colour change in the solution as the free halogen Y_2 is released. F_2 is never used for school displacement tests: it is far too reactive and dangerous (it reacts violently, even explosively, with water and with most other substances). I_2, being the least reactive of the four, cannot displace any of the other three halides.

VN **GIẢI THÍCH TIẾNG VIỆT**

Halogen hoạt động mạnh hơn sẽ **đẩy (thế)** halogen yếu hơn ra khỏi dung dịch muối halogenua của nó, vì dễ nhận electron hơn (tính oxi hoá mạnh hơn). Phản ứng thường nhận biết qua **sự đổi màu dung dịch**. F_2 không bao giờ thử ở trường vì quá nguy hiểm; I_2 là halogen yếu nhất trong 4 chất nên không thể đẩy được halogen nào khác.

Ví dụ mẫu · Displacement: chlorine vs. potassium bromide

Chlorine gas is bubbled through a colourless solution of potassium bromide. Predict what is observed and write the equation.

Chlorine lies above bromine in Group VII, so it is more reactive. It displaces bromine from solution: $Cl_2 + 2KBr -> 2KCl + Br_2$. The colourless solution turns **orange** as bromine is released.

Ví dụ mẫu · Displacement: bromine vs. potassium iodide

Orange bromine water is added to a colourless solution of potassium iodide. Predict what is observed and write the equation.

Bromine lies above iodine in Group VII, so it is more reactive. It displaces iodine from solution: $Br_2 + 2KI -> 2KBr + I_2$. The solution turns **brown** (iodine dissolved in solution; a dark grey-black precipitate of iodine may also appear if excess iodine is formed).

Ví dụ mẫu · Predicting "no reaction"

Iodine crystals are shaken with a colourless solution of potassium chloride. Predict whether a displacement reaction occurs, and explain.

No reaction occurs. Iodine is *below* chlorine in Group VII, so it is *less* reactive than chlorine. A less reactive halogen cannot displace a more reactive one from its salt — only chlorine (or fluorine) could displace iodide, not the reverse.

A halogen displacement reaction is a **redox** reaction (see Unit 6): the halide ion already in solution is **oxidised** (loses an electron) to the free halogen, while the more reactive halogen molecule is **reduced** (gains electrons) to form halide ions. For $Cl_2 + 2KI -> 2KCl + I_2$, the two half-equations are: oxidation, $2I^- -> I_2 + 2e^-$; reduction, $Cl_2 + 2e^- -> 2Cl^-$.

VN **GIẢI THÍCH TIẾNG VIỆT**

Phản ứng thế halogen là một phản ứng **oxi hoá - khử**: ion halogenua trong dung dịch bị **oxi hoá** (mất electron) thành halogen tự do, còn phân tử halogen hoạt động mạnh hơn bị **khử** (nhận electron) thành ion halogenua.

8.4.4 Uses of halogens

Chlorine is added in small, controlled amounts to **drinking water and swimming pools** to kill harmful bacteria (water treatment/sterilisation). Iodine (often as a solution in ethanol, "tincture of iodine") is used as an **antiseptic** to disinfect wounds and skin before surgery, since it kills bacteria on contact.

Halogen	Everyday use	Property being exploited
Chlorine	disinfecting drinking water & swimming pools	kills bacteria (a strong oxidising agent)
Iodine	antiseptic for wounds/skin	kills bacteria on contact

Table 8.4 — Two everyday uses of halogens, each linked to the halogen's chemical reactivity.

Bài tập luyện tập

Which colour change would you observe if chlorine water is added to a colourless solution of potassium iodide?

(A) No change — colourless remains colourless

(B) Colourless to orange

(C) Colourless to brown

(D) Green to colourless

Lời giải chi tiết

Chlorine (more reactive) displaces iodine from potassium iodide: $Cl_2 + 2KI -> 2KCl + I_2$. Iodine dissolved in solution gives a **brown** colour. **(C)**.

Bài tập luyện tập

Explain, in terms of atomic structure, why chlorine is more reactive than bromine.

Lời giải chi tiết

Chlorine atoms have fewer electron shells than bromine atoms, so chlorine's outer shell is closer to the nucleus and less shielded by inner electrons. The incoming electron needed to complete the outer shell is therefore attracted more strongly in chlorine, making it easier to gain an electron — so chlorine is more reactive.

Bài tập luyện tập

Why is fluorine never used in school displacement experiments?

(A) It has no colour change, so results cannot be seen

(B) It is far too reactive and dangerous to handle safely

(C) It does not react with any other halide

(D) It is a solid at room temperature and will not dissolve

Lời giải chi tiết

Fluorine is the most reactive halogen and reacts violently (even explosively) with water and many other substances, making it unsafe for a school laboratory. **(B)**.

Bài tập luyện tập

A solution of sodium astatide, NaAt (astatine, At, lies directly below iodine in Group VII), is treated with bromine water. Predict whether a reaction occurs, and explain.

Lời giải chi tiết

Astatine lies below bromine, so it is *less* reactive than bromine. Bromine, being more reactive, **would** displace astatine from solution: $Br_2 + 2NaAt -> 2NaBr + At_2$ (in practice astatine is intensely radioactive and studied only in trace amounts, but the periodic trend still predicts this outcome).

Bài tập luyện tập

State one everyday use of chlorine and one everyday use of iodine, linking each to a relevant chemical property.

Lời giải chi tiết

Chlorine is used to treat drinking water and swimming pools, because it kills harmful bacteria (a disinfectant/sterilising agent). **Iodine** is used as an antiseptic on skin/wounds, because it also kills bacteria on contact, preventing infection.

Bài tập luyện tập

For the reaction $Br_2 + 2KI -> 2KBr + I_2$, write the two ionic half-equations, and state which species is oxidised and which is reduced.

Lời giải chi tiết

Oxidation (loss of electrons): $2I^- -> I_2 + 2e^-$ — iodide ions are **oxidised**.
Reduction (gain of electrons): $Br_2 + 2e^- -> 2Br^-$ — bromine molecules are **reduced**.

Bài tập luyện tập

Bromine water (orange) is shaken with an unknown colourless halide solution; no colour change is seen. Which halide could this be?

(A) Sodium chloride
(B) Sodium fluoride
(C) Potassium iodide
(D) Lithium bromide

Lời giải chi tiết

Bromine can only displace a halogen *less* reactive than itself (i.e. iodide). It cannot displace fluoride or chloride (both more reactive/above bromine), and lithium bromide already contains bromide — there is no more reactive halogen present to displace, so no reaction is seen with sodium chloride or sodium fluoride. Since only iodide is displaced (giving a colour change), the correct "no reaction" answer here is **(A)** sodium chloride (chlorine is above bromine, so bromine cannot displace it).

8.5 Group 0: the noble gases

8.5.1 Full outer shell and inertness

Helium, neon, argon, krypton, xenon and radon make up **Group 0**, the **noble gases**. Every atom already has a **full outer shell** of electrons (2 for helium, 8 for all the others), so noble gas atoms have no tendency to lose, gain or share electrons with other atoms.

Nhóm 0

Because their outer shell is already complete, noble gases are **monatomic** (they exist as single, separate atoms, not molecules) and are **extremely unreactive** (often described as "inert"). They are all colourless, odourless gases at room temperature, and their boiling points increase down the group as the atoms get larger (stronger, but still weak, intermolecular forces).

VN **GIẢI THÍCH TIẾNG VIỆT**
Nhóm 0 (khí hiếm: He, Ne, Ar, Kr, Xe, Rn) có **lớp electron ngoài cùng đã đầy đủ** (2 với He, 8 với các khí còn lại), nên không có xu hướng nhường, nhận hay dùng chung electron với nguyên tử khác. Vì vậy chúng tồn tại dưới dạng **đơn nguyên tử** và **gần như trơ về mặt hoá học**.

8.5.2 Uses of noble gases

Noble-gas uses exploit their extreme unreactivity, together with their low density or non-flammability:

Noble gas	Boiling point (°C)	Density compared with air	Main use
Helium (He)	-269	much less dense than air	balloons, airships
Neon (Ne)	-246	slightly less dense than air	advertising/discharge lighting
Argon (Ar)	-186	slightly more dense than air	filament lamps, welding shield gas

Table 8.5 — Selected physical properties and uses of He, Ne, Ar. Boiling point rises down the group as the atoms get larger (stronger, though still weak, van der Waals forces between atoms).

Helium: used to fill balloons and airships, since it is far less dense than air *and*, unlike hydrogen, it is completely non-flammable (safe).
Argon: used to fill filament light bulbs, providing an inert atmosphere that stops the hot filament reacting with (and burning away in) oxygen; also used as a shielding gas in welding, forming an inert blanket around the hot metal to keep atmospheric oxygen and nitrogen away from the weld.
Neon: used in advertising signs/discharge lights, glowing a distinctive red-orange colour when a high-voltage current is passed through the low-pressure gas.

VN **GIẢI THÍCH TIẾNG VIỆT**
Ứng dụng khí hiếm dựa trên tính **trơ hoá học** kết hợp với khối lượng riêng thấp hoặc tính không cháy: **Heli** bơm bóng bay/khí cầu (nhẹ hơn không khí, không cháy — an toàn hơn khí hydro); **Argon** dùng trong bóng đèn sợi đốt (tạo môi trường trơ, ngăn dây tóc phản ứng với ôxy) và làm khí bảo vệ khi hàn kim loại (ngăn ôxy/nitơ không khí tiếp xúc mối hàn nóng); **Neon** dùng trong biển quảng cáo, phát sáng màu đỏ-cam đặc trưng khi có dòng điện cao áp chạy qua.

(!) Lỗi thường gặp: Do not write that noble gases are "completely unreactive under all conditions." At IGCSE level they are correctly described as **extremely unreactive / inert**, but under very forcing laboratory conditions the heavier noble gases (with larger, more shielded outer shells) can be made to react: in 1962, chemist Neil Bartlett prepared the first noble-gas compound using xenon, and compounds such as XeF_4 and XeF_2 are now well known. Helium, neon and argon (smaller atoms, outer shell closer to the nucleus) remain effectively unreactive in all ordinary and even extreme conditions. Use "extremely unreactive" rather than an absolute "never reacts" for Group 0 as a whole.

Bài tập luyện tập

Explain, in terms of electronic structure, why helium and neon do not readily form chemical bonds.

Lời giải chi tiết

Their atoms already have a full outer shell of electrons (2 for helium, 8 for neon), so they have no tendency to lose, gain or share electrons — there is no driving force to form a chemical bond.

Bài tập luyện tập

Which noble gas is used inside filament light bulbs, and why?

(A) Helium, because it is the lightest gas

(B) Argon, because its inert atmosphere stops the hot filament reacting with oxygen

(C) Neon, because it produces a bright red glow

(D) Xenon, because it is the densest noble gas

Lời giải chi tiết

Argon provides an inert (unreactive) atmosphere so the very hot filament does not react with oxygen and burn away, extending the bulb's lifetime. **(B)**.

Bài tập luyện tập

Why is helium, rather than hydrogen, generally now used to fill weather balloons and airships despite hydrogen being even less dense?

Lời giải chi tiết

Hydrogen is flammable and can ignite explosively; helium is non-flammable and chemically inert (full outer shell), so it is much safer to use, even though it provides slightly less lift than hydrogen.

Bài tập luyện tập

A student claims "noble gases can never form any chemical compound, under any conditions." Is this statement fully accurate? Explain.

Lời giải chi tiết

Not fully accurate. Noble gases are extremely unreactive, and the lighter ones (He, Ne, Ar) are essentially never observed to react. However, heavier noble gases with larger, more shielded outer shells — particularly xenon — can be forced to react with very reactive elements like fluorine under special laboratory conditions, forming compounds such as XeF_4. The safer, IGCSE-level description is "extremely unreactive" rather than an absolute "never reacts."

Bài tập luyện tập

Argon, rather than air, is used as a shielding gas around the hot metal during welding. Explain why.

Lời giải chi tiết

Air contains reactive gases, particularly oxygen (and, at high temperature, nitrogen), which would react with the very hot molten metal at the weld, weakening it or spoiling the joint. Argon has a full outer shell of electrons and is chemically inert, so it forms a protective blanket around the weld that keeps air away without reacting with the metal itself.

8.6 Transition elements (Supplement)

(Supplement) The block of metals in the centre of the Periodic Table, between Group II and Group III (e.g. iron, copper, zinc, nickel, manganese, chromium, silver), are called the **transition elements**. They share a distinctive set of physical and chemical properties that contrast sharply with the Group I metals.

8.6.1 Typical properties of transition elements

Tính chất kim loại chuyển tiếp (Supplement)

Transition elements are typically: **dense** and **hard**, with **high melting points** (mercury, which is liquid at room temperature, is the main exception); **good conductors** of heat and electricity; they form **coloured** compounds/ions (e.g. Cu^{2+} blue, Fe^{2+} pale green, Fe^{3+} orange-brown, MnO_4^- deep purple); they show **variable oxidation states** in their compounds (e.g. iron forms both Fe^{2+} and Fe^{3+} compounds; copper forms both Cu^+ and Cu^{2+} compounds); and both the elements and their compounds are widely used as **catalysts**.

VN **GIẢI THÍCH TIẾNG VIỆT**

(Supplement) Nguyên tố chuyển tiếp (khối giữa bảng tuần hoàn, ví dụ Fe, Cu, Zn, Ni, Mn, Cr, Ag) thường có: **khối lượng riêng lớn**, **nhiệt độ nóng chảy cao** (trừ thuỷ ngân — lỏng ở nhiệt độ phòng); **dẫn điện/dẫn nhiệt tốt**; tạo hợp chất **có màu**; thể hiện **nhiều mức oxi hoá khác nhau**; và được dùng phổ biến làm **chất xúc tác** trong công nghiệp.

8.6.2 Comparison with Group I

Property	Group I metals	Transition elements
Density	low (Li, Na, K float on water)	high (dense)
Hardness	soft (cut with a knife)	hard and strong
Melting point	low (e.g. Na: $98\,^\circ$C)	generally high (e.g. Fe: $1538\,^\circ$C)
Reaction with cold water	fast/vigorous/violent	little or none (most are unreactive)
Compounds formed	white/colourless, one oxidation state ($+1$)	coloured, variable oxidation states
Use as catalysts	not used (too reactive, unstable)	widely used (Fe, V_2O_5, Pt/Rh, Ni)
Storage	very reactive ones stored under oil	stable in air, no special storage needed

Table 8.6 — Transition elements vs. Group I metals (Supplement): almost every property is reversed between the two blocks.

VN **GIẢI THÍCH TIẾNG VIỆT**

(Supplement) So với Nhóm I, nguyên tố chuyển tiếp gần như **trái ngược hoàn toàn**: đặc/nặng hơn (thay vì nhẹ, nổi trên nước), cứng hơn (thay vì mềm), nhiệt độ nóng chảy cao hơn nhiều, phản ứng với nước lạnh yếu hoặc không phản ứng (thay vì mãnh liệt), hợp chất có màu và nhiều mức oxi hoá (thay vì không màu, chỉ có mức $+1$), và được dùng làm chất xúc tác công nghiệp (kim loại kiềm không được dùng vì quá hoạt động, không bền).

8.6.3 Transition elements as catalysts

A **catalyst** speeds up a chemical reaction without being used up itself. Several transition elements (or their compounds) are essential industrial catalysts:

(Supplement) **Iron,** Fe — catalyst for the **Haber process**, $N_2 + 3H_2 -> 2NH_3$ (manufacture of ammonia).
Vanadium(V) oxide, V_2O_5 — catalyst for the **Contact process**, $2SO_2 + O_2 -> 2SO_3$ (manufacture of sulfuric acid).
Platinum/rhodium, Pt/Rh — catalyst in **catalytic converters**, converting toxic exhaust gases (carbon monoxide, unburnt hydrocarbons, oxides of nitrogen) into CO_2, N_2 and H_2O.
Nickel, Ni — catalyst for the **hydrogenation of vegetable oils** (adding H_2 across $C=C$ double bonds to convert unsaturated liquid oils into saturated solid fats, e.g. in margarine manufacture).

VN GIẢI THÍCH TIẾNG VIỆT
(Supplement) Chất xúc tác công nghiệp tiêu biểu từ nguyên tố chuyển tiếp: **Fe** — quá trình Haber sản xuất amoniac; V_2O_5 — quá trình Contact sản xuất axit sunfuric; **Pt/Rh** — bộ chuyển đổi xúc tác trong ống xả ô tô (khử khí độc); **Ni** — hydro hoá dầu thực vật (biến dầu lỏng chưa bão hoà thành chất béo rắn bão hoà, ví dụ sản xuất margarine).

(Supplement) Transition elements and their compounds are especially good catalysts partly *because* they show variable oxidation states: many transition-metal catalysts work by temporarily changing oxidation state during the reaction (accepting electrons from, or donating electrons to, the reacting molecules), which opens up an alternative reaction pathway of lower activation energy. Group I metals, which have only one fixed oxidation state ($+1$) and are, in any case, far too reactive and unstable to remain chemically unchanged, cannot function this way as catalysts.

Ví dụ mẫu · Identifying industrial catalysts (Supplement)

(Supplement) For each industrial process below, name the catalyst used: (a) the Haber process; (b) the Contact process; (c) catalytic converters in car exhausts; (d) hydrogenation of vegetable oils to make margarine.

(a) **Iron,** Fe. (b) **Vanadium(V) oxide,** V_2O_5. (c) **Platinum and rhodium,** Pt/Rh. (d) **Nickel,** Ni.

Ví dụ mẫu · Transition element vs. Group I metal (Supplement)

(Supplement) Compare iron and sodium directly under these headings: density, melting point, reaction with cold water, and colour of compounds formed.

Density: iron is dense ($7.9\,g/cm^3$); sodium has low density ($0.97\,g/cm^3$, floats on water).
Melting point: iron has a very high melting point ($1538\,°C$); sodium has a low melting point ($98\,°C$).
Reaction with cold water: iron reacts only extremely slowly (rusts over time, in the presence of oxygen and water); sodium reacts vigorously and immediately, releasing hydrogen gas.
Compounds: iron forms coloured compounds in two common oxidation states, pale green Fe^{2+} and orange-brown Fe^{3+}; sodium forms colourless/white compounds in a single oxidation state, Na^+.

Bài tập luyện tập

(Supplement) Which property is typical of transition elements but *not* typical of Group I metals?

(A) Solid at room temperature
(B) Forms coloured compounds and shows variable oxidation states
(C) Reacts with chlorine to form a chloride
(D) Conducts electricity

Lời giải chi tiết

Group I metals are also solid, react with chlorine, and conduct electricity — but they form colourless compounds with only one oxidation state ($+1$), unlike transition elements. **(B)**.

Bài tập luyện tập

(Supplement) Name the catalyst used in the Contact process, and write the equation for the reaction it catalyses.

Lời giải chi tiết

Catalyst: **vanadium(V) oxide,** V_2O_5. Reaction: $2SO_2 + O_2 -> 2SO_3$.

Bài tập luyện tập

(Supplement) Explain why sodium is never used as an industrial catalyst, even though some transition metals are.

Lời giải chi tiết

Sodium is far too reactive and unstable to serve as a catalyst: it would react immediately and vigorously with moisture or other substances present in an industrial reactor (e.g. with water vapour, releasing hydrogen and heat), rather than remaining chemically unchanged as a true catalyst must. Transition metals such as iron and nickel are much less reactive and remain stable under reaction conditions, allowing them to speed up reactions repeatedly without being consumed.

Bài tập luyện tập

(Supplement) A pale green solution containing Fe^{2+} ions is left standing in air and slowly turns orange-brown. State what has happened, and explain why this behaviour is typical of a transition element but would not be seen with a Group I ion.

Lời giải chi tiết

The pale green Fe^{2+} ion has been oxidised by oxygen in the air to orange-brown Fe^{3+}. This is possible because iron, a transition element, shows **variable oxidation states** ($+2$ and $+3$) and forms differently coloured compounds/ions in each state. Group I metals form only one oxidation state ($+1$), so no such colour change between oxidation states is possible for a Group I ion.

Bài tập luyện tập

(Supplement) Name the catalyst used in the hydrogenation of vegetable oils, and state the type of bond that is broken/reacted with in this process.

Lời giải chi tiết

Catalyst: **nickel,** Ni. Hydrogen gas adds across the carbon-carbon **double bonds** ($C=C$) present in unsaturated vegetable oils, converting them into saturated (single $C-C$ bonds) solid fats.

Bài tập luyện tập

(Supplement) A catalytic converter fitted to a car's exhaust system contains platinum and rhodium. State two toxic gases it helps remove, and the harmless products they are converted into.

Lời giải chi tiết

Carbon monoxide, CO, and oxides of nitrogen, NO_x (together with unburnt hydrocarbons), pass over the platinum/rhodium catalyst and are converted into the harmless gases carbon dioxide (CO_2), nitrogen (N_2) and water vapour (H_2O).

Bài tập luyện tập

(Supplement) Explain briefly why transition metals and their compounds make such effective catalysts, linking your answer to their variable oxidation states.

Lời giải chi tiết

Because transition elements can exist in more than one oxidation state, they can temporarily gain or lose electrons during a reaction — accepting electrons from, or donating electrons to, the reacting substances — and then return to their original oxidation state at the end. This provides an alternative reaction route with a lower activation energy, speeding up the reaction, while the catalyst itself is chemically unchanged overall once the reaction is complete.

Metals

Mục tiêu Unit: Giải thích tính chất chung của kim loại từ liên kết kim loại; ghi nhớ và vận dụng dãy hoạt động hoá học; dự đoán phản ứng thế (displacement); trình bày chi tiết lò cao sản xuất sắt và điện phân nhôm; hiểu vì sao hợp kim cứng hơn kim loại nguyên chất; giải thích cơ chế gỉ sét và các phương pháp chống gỉ, kể cả lợi ích của tái chế kim loại.

9.1 General properties of metals

Roughly three-quarters of all elements are metals. Their characteristic physical properties all follow directly from **metallic bonding**: a giant lattice of positive metal ions held together by a "sea" of **delocalised electrons** that belong to the structure as a whole, not to any one ion.

Metallic bonding — quick recap

In a metal, each atom loses its outer-shell electron(s) into a shared, mobile "electron sea". The result is a regular, close-packed lattice of positive ions immersed in delocalised electrons. The strong electrostatic attraction between the positive ions and this negative electron sea acts equally in all directions and is not broken when the ions shift position — this single idea explains every property below.

VN **GIẢI THÍCH TIẾNG VIỆT**

Trong kim loại, các nguyên tử nhường electron lớp ngoài cùng vào một "biển electron" chung, tạo ra mạng tinh thể gồm các ion dương được bao quanh bởi electron tự do (không thuộc riêng nguyên tử nào). Lực hút tĩnh điện giữa ion dương và biển electron này tác dụng theo mọi hướng và không bị phá vỡ khi các lớp ion trượt lên nhau — đây là chìa khoá giải thích toàn bộ tính chất vật lý của kim loại.

9.1.1 Electrical and thermal conductivity

Metals conduct electricity well, in both the solid and molten state, because the delocalised electrons are free to move through the whole lattice and carry charge when a voltage is applied. The same mobile electrons also transfer kinetic energy rapidly by colliding with neighbouring ions, which is why metals are excellent thermal conductors. **Uses:** copper and aluminium for electrical wiring and overhead cables; copper and aluminium for saucepan bases and heat sinks/radiators.

VN **GIẢI THÍCH TIẾNG VIỆT**

Electron tự do di chuyển khắp mạng tinh thể nên mang được điện tích (dẫn điện) và truyền động năng nhanh qua va chạm giữa các ion (dẫn nhiệt) — cả ở thể rắn lẫn thể lỏng. Vì vậy đồng và nhôm được dùng làm dây điện, và đồng/nhôm được dùng làm đáy nồi, bộ tản nhiệt.

9.1.2 Malleability and ductility

Metals are **malleable** (can be hammered or rolled into sheets) and **ductile** (can be drawn into wires) because the layers of positive ions can slide over one another under stress *without breaking the*

metallic bond — the non-directional electron sea simply re-forms around the ions in their new positions. This contrasts sharply with ionic crystals, which shatter when struck because sliding brings like-charged ions together, causing repulsion and fracture. **Uses:** aluminium rolled into kitchen foil and drinks cans; copper and gold drawn into fine wire.

VN **GIẢI THÍCH TIẾNG VIỆT**

Khi có lực tác dụng, các lớp ion dương có thể trượt lên nhau mà liên kết kim loại không bị đứt, vì biển electron tự do bao quanh linh hoạt, tái sắp xếp ngay quanh vị trí ion mới. Đây là lý do kim loại dễ dát mỏng (malleable) và kéo sợi (ductile) — khác hẳn tinh thể ion, vốn giòn và vỡ vụn khi bị đập vì các ion cùng dấu bị đẩy lại gần nhau.

9.1.3 High melting and boiling points

Overcoming the strong, many-ion electrostatic attraction in the lattice requires a large amount of energy, so most metals have high melting and boiling points (e.g. iron melts at $1538\,^{\circ}$C). The strength of the attraction — and hence the melting point — generally increases with a smaller ionic radius, a higher ionic charge, and more delocalised electrons per atom. (Exceptions exist, e.g. sodium, mp only $98\,^{\circ}$C, has just one delocalised electron per ion and a relatively large ionic radius.) **Uses:** iron/steel and tungsten (very high mp) in furnaces, engines, and lamp filaments.

VN **GIẢI THÍCH TIẾNG VIỆT**

Lực hút tĩnh điện mạnh giữa nhiều ion dương và electron tự do đòi hỏi rất nhiều năng lượng để phá vỡ, nên đa số kim loại có nhiệt độ nóng chảy/sôi cao. Lực hút càng mạnh khi bán kính ion càng nhỏ, điện tích ion càng lớn, và số electron tự do trên mỗi ion càng nhiều.

9.1.4 Lustre and sonority

Freshly cut or polished metal surfaces are **shiny (lustrous)**: the mobile delocalised electrons absorb and instantly re-emit light at the surface, reflecting it. Most metals are also **sonorous** — they produce a clear, ringing sound when struck, because the rigid regular lattice vibrates in a characteristic way (unlike a dull, amorphous or porous material, which damps the vibration). **Uses:** gold and silver in jewellery; bronze in bells and cymbals.

VN **GIẢI THÍCH TIẾNG VIỆT**

Bề mặt kim loại sáng bóng vì electron tự do hấp thụ và phản xạ lại ánh sáng ngay lập tức. Kim loại cũng phát ra âm thanh vang (sonorous) khi gõ vào, do mạng tinh thể đều đặn rung theo cách đặc trưng — vì vậy vàng, bạc dùng làm trang sức, còn đồng thanh (bronze) dùng đúc chuông, chũm choẹ.

Property	Reason (metallic bonding)	Typical use
Good electrical conductor	delocalised electrons carry charge	wiring, cables (Cu, Al)
Good thermal conductor	delocalised electrons transfer kinetic energy	pans, heat sinks (Cu, Al)
Malleable / ductile	ion layers slide without breaking the bond	foil, wire, sheet metal
High melting point	strong attraction between ions and electron sea	furnace parts, filaments
Shiny (lustrous)	free electrons reflect light at the surface	jewellery, mirrors, trim
Sonorous	rigid regular lattice rings when struck	bells, cymbals

General physical properties of metals, linked to metallic bonding, with typical uses.

9.2 The reactivity series

The **reactivity series** ranks metals in order of how readily their atoms lose electrons to form positive ions — that is, how easily they are **oxidised**. A more reactive metal loses electrons more readily than a less reactive one.

> **Reactivity series (most to least reactive):**
> Potassium (K) > Sodium (Na) > Calcium (Ca) > Magnesium (Mg) > Aluminium (Al) > *(Carbon)* > Zinc (Zn) > Iron (Fe) > *(Hydrogen)* > Copper (Cu) > Silver (Ag) > Gold (Au).

VN **GIẢI THÍCH TIẾNG VIỆT**

Dãy hoạt động hoá học xếp các kim loại theo khả năng **nhường electron** để tạo ion dương (bị oxi hoá). Kim loại càng đứng trên trong dãy càng dễ nhường electron → càng phản ứng mạnh với nước, hơi nước, axit loãng, và càng khó tách ra khỏi hợp chất của nó trong tự nhiên.

9.2.1 Why carbon and hydrogen are included as reference points

Carbon and hydrogen are *not metals*, yet both are conventionally placed inside the series as benchmarks, because each answers a practical question:

- **Carbon's position** tells us whether a metal's ore can be reduced cheaply using carbon (coke) in a furnace. Metals *below* carbon (Zn, Fe, Cu, …) have oxides that carbon can reduce, because carbon is more reactive than they are and "wins" the oxygen. Metals *above* carbon (K, Na, Ca, Mg, Al) are more reactive than carbon, so carbon cannot remove oxygen from their compounds — these metals must be extracted by electrolysis instead.
- **Hydrogen's position** tells us whether a metal reacts with dilute acids to release hydrogen gas. Metals *above* hydrogen displace it from dilute acids (they are more reactive than hydrogen); metals *below* hydrogen (Cu, Ag, Au) do not react with dilute acids at all.

VN **GIẢI THÍCH TIẾNG VIỆT**

Carbon và hydro không phải kim loại nhưng được dùng làm **mốc so sánh**. Vị trí của carbon quyết định kim loại có thể tách bằng cách khử với carbon hay không (kim loại kém hoạt động hơn carbon thì được — vì carbon "giành" oxy tốt hơn; kim loại hoạt động hơn carbon thì không, phải điện phân). Vị trí của hydro quyết định kim loại có phản ứng với axit loãng giải phóng khí hydro hay không (kim loại hoạt động hơn hydro thì có; kém hơn thì không).

9.2.2 Reactions with cold water, steam and dilute acid

Reactivity decreases down the series, so reactions with water and acid become progressively less vigorous, and eventually stop altogether.

Metal	Cold water	Steam	Dilute acid	Extraction method
Potassium (K)	violent; floats, melts, catches fire, darts around	(too dangerous to test)	(too dangerous to test)	electrolysis of molten compound
Sodium (Na)	vigorous; floats, fizzes, melts into a ball	violent	(too dangerous to test)	electrolysis of molten compound
Calcium (Ca)	steady effervescence; $Ca(OH)_2$ forms (milky)	vigorous	vigorous	electrolysis of molten compound
Magnesium (Mg)	very slow (fine bubbles over days)	burns brightly; MgO + H_2	vigorous, rapid fizzing	electrolysis of molten compound
Aluminium (Al)	none (protective Al_2O_3 layer)	none (oxide layer resists)	slow start, then moderate once oxide layer is breached	electrolysis of molten compound
(Carbon)	—	—	—	*reference point*
Zinc (Zn)	none	reacts; ZnO + H_2	moderate	reduction with carbon/CO
Iron (Fe)	none (rusts slowly, needs O_2 *and* H_2O)	reacts reversibly; Fe_3O_4 + H_2	slow	reduction with carbon/CO (blast furnace)
(Hydrogen)	—	—	—	*reference point*
Copper (Cu)	none	none	none	roasted from sulfide ore; refined by electrolysis
Silver (Ag)	none	none	none	found mostly native / trace by-product of other ores
Gold (Au)	none	none	none	found native (uncombined)

The reactivity series with reactions and industrial extraction method for each metal.

Some illustrative equations (all state symbols omitted for clarity):

$$2K + 2H_2O -> 2KOH + H_2 \qquad Ca + 2H_2O -> Ca(OH)_2 + H_2 \qquad Mg + 2HCl -> MgCl_2 + H_2$$

$$Zn + H_2O(steam) -> ZnO + H_2 \qquad 3Fe + 4H_2O(steam) <=> Fe_3O_4 + 4H_2$$

(!) Lỗi thường gặp: Aluminium *looks* unreactive with water because a thin, tough, continuous layer of aluminium oxide forms instantly on its surface and protects the metal underneath — this is **passivation**, not low reactivity. Aluminium is in fact well above zinc and iron in the true reactivity series; once the oxide layer is removed or broken (e.g. by dilute acid or by amalgamation), aluminium reacts readily.

VN **GIẢI THÍCH TIẾNG VIỆT**

Nhôm có vẻ "trơ" với nước vì lớp oxit nhôm mỏng, bền, bao phủ ngay lập tức bảo vệ bề mặt kim loại — đây là hiện tượng **thụ động hoá (passivation)**, không phải do nhôm kém hoạt động. Thực chất nhôm đứng khá cao trong dãy hoạt động, chỉ cần phá lớp oxit là phản ứng xảy ra mạnh.

9.3 Displacement reactions

The displacement rule

A more reactive metal will **displace** (push out) a less reactive metal from an aqueous solution of the less reactive metal's salt, or from its oxide. The more reactive metal loses electrons to become the ion in solution, while the less reactive metal's ion gains those electrons and is deposited as the free metal.

VN **GIẢI THÍCH TIẾNG VIỆT**

Kim loại hoạt động mạnh hơn sẽ **đẩy** kim loại yếu hơn ra khỏi dung dịch muối (hoặc oxit) của nó. Kim loại mạnh hơn nhường electron để thành ion tan trong dung dịch, còn ion của kim loại yếu hơn nhận electron và bị tách ra thành kim loại tự do (kết tủa/bám vào).

Ví dụ 1 · Predicting a displacement — Mg + zinc sulfate

Predict, with a reason, what happens when magnesium ribbon is placed into zinc sulfate solution.

Reasoning: Mg lies above Zn in the reactivity series, so Mg is more reactive and displaces Zn from solution.

$$Mg + ZnSO_4 -> MgSO_4 + Zn$$

Observation: a grey deposit of zinc metal forms on the magnesium ribbon, the solution becomes less concentrated in Zn^{2+}, and the reaction is exothermic (temperature rises).

Ví dụ 2 · Predicting a displacement — Fe + copper sulfate

Predict what happens when iron filings are added to blue copper(II) sulfate solution.

Reasoning: Fe is above Cu in the reactivity series, so iron is more reactive and displaces copper.

$$Fe + CuSO_4 -> FeSO_4 + Cu$$

Observation: the blue colour of the solution fades (as Cu^{2+} is used up and pale green Fe^{2+} forms), and a reddish-brown deposit of copper metal appears on the iron.

Ví dụ 3 · Predicting "no reaction" — Cu + zinc sulfate

Predict what happens when copper turnings are added to zinc sulfate solution.

Reasoning: Cu lies *below* Zn in the reactivity series — copper is *less* reactive than zinc. A less reactive metal cannot displace a more reactive metal from its salt.

$$Cu + ZnSO_4 -> \text{no reaction}$$

Observation: no colour change, no deposit — the copper and the colourless zinc sulfate solution remain unchanged.

(!) Lỗi thường gặp: Displacement only runs "downhill" the reactivity series. Before writing an equation, always check which of the two metals is higher in the series — many marks are lost by students who write a displacement equation for a pair where, in fact, no reaction occurs (as in Ví dụ 3 above).

9.3.1 Thermite reaction

The **thermite reaction** is a displacement reaction between aluminium powder and iron(III) oxide, ignited with a magnesium fuse:

$$2Al + Fe_2O_3 -> Al_2O_3 + 2Fe$$

Ví dụ 4 · Thermite reaction and its use in welding railway tracks

Powdered aluminium is mixed with iron(III) oxide powder and ignited. Explain what happens and describe a practical use.

Explanation: aluminium is well above iron in the reactivity series, so it is more reactive and displaces iron from its oxide, as shown above. The reaction is **extremely exothermic**: the temperature reaches around $2500\,^{\circ}$C, easily high enough to melt the iron product (Fe, mp $1538\,^{\circ}$C) as it forms, along with molten Al_2O_3 slag which floats above it (lower density).

Use — welding railway tracks: a mould is clamped around the gap between two rail ends, and a crucible of thermite mixture above it is ignited. The molten iron flows down into the mould and fuses the two rail ends into one continuous, seamless joint as it cools and solidifies. This method (aluminothermic welding) is valued because it needs no external electricity supply and can be carried out on-site, in the field, to repair or join track quickly.

VN **GIẢI THÍCH TIẾNG VIỆT**

Phản ứng nhiệt nhôm (thermite): bột nhôm đẩy sắt ra khỏi oxit sắt(III) vì nhôm hoạt động mạnh hơn sắt, toả nhiệt cực lớn (khoảng $2500\,^{\circ}$C) đủ làm sắt nóng chảy ngay khi vừa tạo thành. Ứng dụng quan trọng: hàn đường ray xe lửa tại chỗ, không cần nguồn điện, vì sắt lỏng chảy vào khuôn nối liền hai đoạn ray.

Ví dụ 5 · Using displacement results to rank unknown metals

Metals X, Y and Z are tested by adding each to solutions of the salts of the others. Results: X displaces Y from its salt solution; Z displaces X from its salt solution; Y does not displace Z. Rank X, Y, Z from most to least reactive.

Reasoning: "X displaces Y" means X is more reactive than Y (X $>$ Y). "Z displaces X" means Z $>$ X. "Y does not displace Z" is consistent with Z $>$ Y, confirming the order rather than contradicting it.

Order (most to least reactive): Z $>$ X $>$ Y.

Ví dụ 6 · Rate of reaction with dilute acid

Equal-sized ribbons/pieces of magnesium, zinc and iron are each added to separate test tubes of dilute hydrochloric acid of the same concentration, and the volume of gas produced is measured over time. Predict and explain the order in which the three metals produce gas fastest.

Reasoning: all three metals lie above hydrogen, so all three react, releasing hydrogen gas:

$$Mg + 2HCl -> MgCl_2 + H_2 \qquad Zn + 2HCl -> ZnCl_2 + H_2 \qquad Fe + 2HCl -> FeCl_2 + H_2$$

The rate at which each metal loses electrons to the acid depends on how reactive it is: a more reactive metal gives up its electrons more readily, so the reaction proceeds faster and more gas is collected per minute.

Order of rate (fastest to slowest): magnesium $>$ zinc $>$ iron — matching their order in the reactivity series. The same total volume of gas is eventually produced by an equal number

of moles of each metal, but magnesium reaches that volume in the shortest time (steepest gas-volume/time graph), and iron the longest.

VN **GIẢI THÍCH TIẾNG VIỆT**

Cả ba kim loại Mg, Zn, Fe đều đứng trên hydro nên đều phản ứng với axit loãng, giải phóng khí hydro. Kim loại càng hoạt động mạnh thì nhường electron cho axit càng nhanh → tốc độ thoát khí càng nhanh. Do đó thứ tự tốc độ phản ứng (nhanh nhất đến chậm nhất) đúng bằng thứ tự trong dãy hoạt động: Mg > Zn > Fe.

9.4 Extraction of metals

The industrial method used to extract a metal from its ore is determined entirely by the metal's position in the reactivity series relative to carbon and hydrogen.

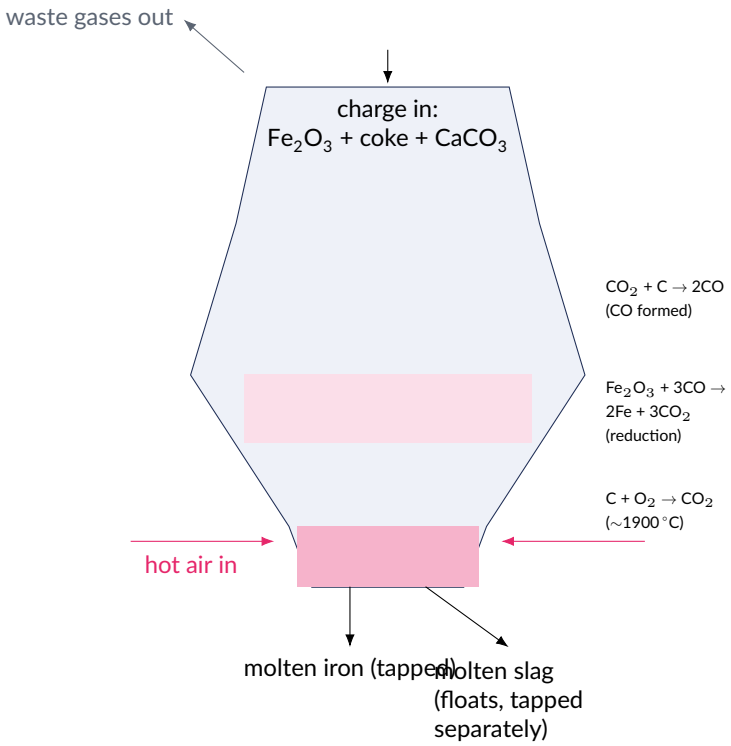
Above carbon (K, Na, Ca, Mg, Al): too reactive to be reduced by carbon → extracted by **electrolysis** of the molten compound.
Below carbon, above hydrogen (Zn, Fe): reduced economically using **carbon or carbon monoxide** in a furnace.
Below hydrogen (Cu, Ag, Au): unreactive enough to occur **native (uncombined)**, or obtainable by simple heating/roasting of the ore in air.

VN **GIẢI THÍCH TIẾNG VIỆT**

Phương pháp tách kim loại phụ thuộc hoàn toàn vào vị trí của nó so với carbon và hydro trong dãy hoạt động: kim loại hoạt động hơn carbon → điện phân hợp chất nóng chảy (tốn nhiều điện năng, chi phí cao); kim loại kém hoạt động hơn carbon nhưng hoạt động hơn hydro → khử bằng carbon/CO (rẻ hơn); kim loại kém hoạt động hơn hydro → có thể tồn tại ở dạng đơn chất trong tự nhiên hoặc chỉ cần nung nhẹ.

9.4.1 The blast furnace — extraction of iron

Iron is extracted from haematite ore (mainly iron(III) oxide, Fe_2O_3) in a **blast furnace**. The raw materials — iron ore, coke (carbon), and limestone ($CaCO_3$) — are charged in continuously from the top, while a blast of hot air is blown in near the base through nozzles called **tuyeres**.



Blast furnace cross-section: raw materials charged from the top; hot air blown in at the base; iron ore is reduced as it descends; molten iron and slag collect at the bottom and are tapped off separately.

Ví dụ 7 · The three key reactions of the blast furnace

Write and explain the three main reactions that take place inside the blast furnace.

Reaction 1 — combustion of coke (provides heat): hot air blown in near the base burns the coke, releasing a large amount of heat and raising the temperature near the bottom to about $1900\,^{\circ}\text{C}$.

$$C + O_2 -> CO_2$$

Reaction 2 — formation of the reducing agent: as the hot CO_2 rises through more incandescent coke higher up, it is itself reduced to carbon monoxide.

$$CO_2 + C -> 2CO$$

Reaction 3 — reduction of the iron ore (the key extraction step): carbon monoxide, a stronger reducing agent than carbon itself at these temperatures, removes the oxygen from the descending iron ore.

$$Fe_2O_3 + 3CO -> 2Fe + 3CO_2$$

Molten iron trickles down and collects at the bottom of the furnace, where it is tapped off periodically (this impure "pig iron"/cast iron contains about 4% carbon and other impurities).

Ví dụ 8 · Role of limestone — flux and slag formation

Explain the purpose of adding limestone to the blast furnace, giving both relevant equations.

Limestone decomposes in the heat of the furnace (**thermal decomposition**):

$$CaCO_3 -> CaO + CO_2$$

The calcium oxide (a basic oxide) then reacts with silicon dioxide, SiO_2 — an acidic impurity present in the iron ore (sand/rock) — to form calcium silicate (**slag**):

$$CaO + SiO_2 -> CaSiO_3$$

Molten slag is less dense than molten iron, so it floats on top and is tapped off separately near the top of the liquid zone. This removes the rocky impurity from the iron and produces slag which is sold for road building and cement manufacture.

VN **GIẢI THÍCH TIẾNG VIỆT**

Lò cao: nguyên liệu (quặng sắt Fe_2O_3, than cốc, đá vôi $CaCO_3$) nạp từ đỉnh, khí nóng thổi vào từ đáy. Ba phản ứng chính: (1) than cốc cháy toả nhiệt $C + O_2 -> CO_2$; (2) CO_2 bị khử tiếp thành khí CO $CO_2 + C -> 2CO$; (3) CO khử quặng sắt thành sắt lỏng $Fe_2O_3 + 3CO -> 2Fe + 3CO_2$. Đá vôi phân huỷ $CaCO_3 -> CaO + CO_2$ rồi CaO phản ứng với tạp chất SiO_2 tạo xỉ (slag) $CaO + SiO_2 -> CaSiO_3$ nổi lên trên, tách riêng khỏi sắt lỏng.

9.4.2 Electrolysis of aluminium oxide

Aluminium lies above carbon in the reactivity series, so its ore (purified to alumina, Al_2O_3, from bauxite) cannot be reduced by carbon. Because pure Al_2O_3 melts above $2000\,^\circ$C, it is first dissolved in molten **cryolite** (Na_3AlF_6) to lower the operating temperature to around $950\,^\circ$C, and the mixture is electrolysed using carbon (graphite) electrodes:

$$\text{cathode: } Al^{3+} + 3e^- -> Al \qquad \text{anode: } 2O^{2-} -> O_2 + 4e^-$$

$$\text{overall: } 2Al_2O_3 -> 4Al + 3O_2$$

Molten aluminium (denser than the electrolyte) collects at the cathode/base of the cell and is siphoned off; the graphite anodes are gradually burnt away by the oxygen produced ($C + O_2 -> CO_2$) and must be replaced periodically. This process consumes very large amounts of electrical energy, which is why aluminium extraction (and hence aluminium metal) is comparatively expensive. (Full detail of the electrolysis cell is covered in Unit 4, Electrochemistry.)

VN **GIẢI THÍCH TIẾNG VIỆT**

Nhôm hoạt động mạnh hơn carbon nên không thể khử bằng carbon; phải điện phân nhôm oxit nóng chảy (hoà tan trong criolit để hạ nhiệt độ nóng chảy từ trên $2000\,^\circ$Cxuống còn khoảng $950\,^\circ$C). Quá trình này tiêu tốn rất nhiều điện năng, khiến nhôm có giá thành cao hơn sắt dù trữ lượng quặng rất dồi dào. Chi tiết đầy đủ xem lại Unit 4 (Điện phân).

9.4.3 Reduction of zinc — a second worked example below carbon

Zinc's main ore, zinc blende, is largely zinc sulfide (ZnS). Because carbon cannot reduce a sulfide directly, the ore is first **roasted** (heated strongly in air) to convert it to zinc oxide:

$$2ZnS + 3O_2 -> 2ZnO + 2SO_2$$

The zinc oxide is then reduced using carbon (or carbon monoxide) in a furnace, exactly as for iron:

$$ZnO + C -> Zn + CO$$

Since zinc's boiling point ($907\,^\circ$C) is lower than the temperature of the furnace, the zinc is produced as a vapour and condensed and collected separately from the waste gases.

VN **GIẢI THÍCH TIẾNG VIỆT**

Quặng kẽm chủ yếu là kẽm sunfua (ZnS), được nung trong không khí (roasting) để chuyển thành kẽm oxit ($2ZnS + 3O_2 -> 2ZnO + 2SO_2$), sau đó khử bằng carbon giống như sắt: $ZnO + C -> Zn + CO$. Vì kẽm sôi ở nhiệt độ thấp hơn nhiệt độ lò, kẽm kim loại bay hơi và được ngưng tụ tách riêng.

9.4.4 Metals below hydrogen

Copper, silver and gold are so unreactive that they resist forming compounds in the environment. Gold is found almost entirely **native** (as the free metal). Silver occurs mostly native or as a by-product of extracting other metals. Copper is usually combined in sulfide or oxide ores; it is extracted by **roasting** the ore in air (heating strongly, which is enough to release the unreactive metal, unlike for more reactive metals) and then purified to high purity by electrolytic refining, since even small impurities reduce its electrical conductivity.

Ví dụ 9 · Choosing the correct extraction method

State and justify the extraction method for: (a) sodium, (b) zinc, (c) gold, (d) aluminium.

(a) Sodium — far above carbon in the series → **electrolysis** of molten sodium chloride.
(b) Zinc — below carbon, above hydrogen → **reduction with carbon/carbon monoxide** in a furnace.
(c) Gold — far below hydrogen, essentially unreactive → **found native**, separated physically (e.g. by density) rather than chemically.
(d) Aluminium — above carbon in the series (despite appearing unreactive due to its protective oxide layer) → **electrolysis** of molten Al_2O_3 in cryolite.

9.5 Alloys

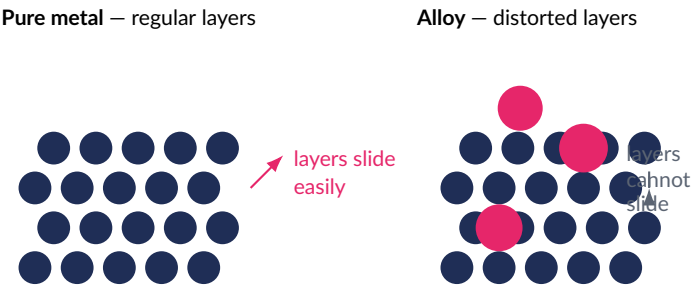
An **alloy** is a mixture of a metal with one or more other elements (often other metals, or a non-metal such as carbon), designed to have more useful properties than the pure metal.

Why alloys are harder than pure metals

In a pure metal, all the atoms are the same size, so they pack into perfectly regular layers that can slide over each other relatively easily when a force is applied — this is why pure metals tend to be comparatively soft. In an alloy, atoms of a different element (often a different size) are mixed in among the original metal atoms. These different-sized atoms **distort the regular layers**, so the layers can no longer slide smoothly past one another. This hinders "slip" between layers, making alloys harder and stronger — though usually less malleable — than the pure metal.

VN **GIẢI THÍCH TIẾNG VIỆT**

Ở kim loại nguyên chất, các nguyên tử cùng kích thước xếp thành lớp đều đặn, dễ trượt lên nhau → kim loại nguyên chất khá mềm. Trong hợp kim, các nguyên tử nguyên tố khác (thường khác kích thước) chen vào giữa, làm **méo mó** cấu trúc lớp đều đặn, khiến các lớp **khó trượt** lên nhau hơn → hợp kim cứng và bền hơn kim loại nguyên chất (nhưng thường kém dẻo hơn).



Left: in a pure metal, identical atoms form regular layers that slip past each other easily. Right: larger foreign atoms (pink) in an alloy distort the layers, blocking slip and making the alloy harder.

Ví dụ 10 · Explaining alloy hardness

Mild steel (iron with a small percentage of carbon) is much harder than pure iron. Explain why, referring to the structure.

Pure iron has atoms of a single, uniform size arranged in regular layers, so under stress these layers slide past each other fairly easily, making pure iron relatively soft and malleable. Adding a small amount of carbon introduces much smaller atoms that sit awkwardly among the iron atoms, distorting the regular layered arrangement. This disruption prevents the layers from sliding smoothly over each other, so a much larger force is needed to deform the structure — mild steel is therefore significantly harder than pure iron.

9.5.1 Common named alloys

Alloy	Composition	Typical use
Brass	copper + zinc	taps, door fittings, musical instruments (decorative, corrosion-resistant)
Bronze	copper + tin	statues, medals, ship propellers, bearings
Mild steel	iron + a small % carbon (~0.25%)	car bodies, ship hulls, girders, machinery (strong, still malleable)
Stainless steel	iron + chromium + nickel	cutlery, surgical instruments, kitchen sinks, chemical plant (resists rusting)
Duralumin (Supplement)	aluminium + a little copper (and Mg, Mn)	aircraft bodies, bicycle frames (nearly as light as Al, much stronger)

Common alloys: composition and typical use.

VN **GIẢI THÍCH TIẾNG VIỆT**

Một số hợp kim quan trọng: **đồng thau (brass)** = đồng + kẽm (vòi nước, phụ kiện cửa); **đồng thanh (bronze)** = đồng + thiếc (tượng, huy chương); **thép thường (mild steel)** = sắt + một ít carbon (thân xe, vỏ tàu — vẫn khá dẻo vì tỉ lệ carbon thấp); **thép không gỉ (stainless steel)** = sắt + crom + niken (dao kéo, dụng cụ y tế — chống gỉ); **duralumin** (Nâng cao) = nhôm + một ít đồng — nhẹ gần bằng nhôm nguyên chất nhưng bền hơn nhiều, dùng làm khung máy bay.

9.6 Rusting and its prevention

Rusting is the corrosion of iron (and steel). It produces a flaky, orange-brown solid, hydrated iron(III) oxide:

$$Fe_2O_3 \cdot xH_2O$$

Conditions needed for rusting

Rusting requires *both* oxygen *and* water to be present at the same time. If either is absent, iron does not rust.

$$\text{iron} + \text{oxygen} + \text{water} \rightarrow \text{hydrated iron(III) oxide (rust)}$$

VN **GIẢI THÍCH TIẾNG VIỆT**

Gỉ sét là sự ăn mòn của sắt, tạo ra oxit sắt(III) ngậm nước ($Fe_2O_3 \cdot xH_2O$), màu nâu đỏ, xốp, dễ bong tróc. Điều kiện **bắt buộc phải có cả hai**: oxy **và** nước — thiếu một trong hai thì sắt không gỉ.

9.6.1 Experimental test for the conditions needed for rusting

A classic experiment uses three test tubes, each containing a clean iron nail:

Tube	Set-up	Result
1	nail + dry air, sealed with anhydrous calcium chloride (drying agent) to keep air moisture-free	no rust — water absent
2	nail + boiled (de-oxygenated) water, topped with a layer of oil to stop air re-dissolving	no rust — oxygen absent
3	nail + ordinary tap water, left open to the air	rusts — both oxygen (dissolved & from the air) and water present

Classic three-tube experiment showing rusting needs both oxygen and water.

Because rusting occurs only in tube 3, where both oxygen and water are present together, the experiment confirms that both substances are necessary.

(!) Lỗi thường gặp: A very common error is to say iron rusts simply because it is "exposed to water" or "exposed to air". Neither statement alone is correct — the requirement is strictly **both oxygen and water together**. A nail in boiled, oil-sealed water (oxygen removed) does not rust, and a nail in dry air (water removed) does not rust either.

9.6.2 Methods of preventing rusting

Method	How it works	Example use
Painting / oiling / greasing	barrier excludes oxygen and water from the iron surface	car bodies, bridges, bicycle chains, tools
Plastic coating	barrier excludes oxygen and water; also decorative	dish racks, bike baskets, wire fencing
Electroplating with tin	barrier only — tin is less reactive than iron, so protection is lost *immediately* once scratched (exposed iron then corrodes faster)	food/drink cans
Electroplating with chromium	barrier, plus decorative shine; chromium's own oxide layer is fairly protective	car bumpers, taps, bicycle parts
Galvanising (zinc coating)	barrier *and* sacrificial protection — zinc is more reactive than iron, so even where scratched, zinc corrodes preferentially	buckets, nails, roofing sheets, street furniture
Sacrificial anodes	blocks of a more reactive metal (Zn or Mg) bolted on; corrode instead of the iron/steel, and are replaced periodically	ship hulls, underground pipelines, oil rigs
Alloying (stainless steel)	chromium forms a thin, tough, self-healing Cr_2O_3 layer that will not flake off	cutlery, surgical instruments, sinks

Summary of methods used to prevent or slow the rusting of iron and steel.

(!) Lỗi thường gặp: Do not confuse **galvanising** with ordinary barrier plating (e.g. tin-plating). Both initially work as a physical barrier, but *only* galvanising also gives **sacrificial protection**: because zinc is more reactive than iron, zinc continues to protect the iron even after the coating is scratched or damaged, since the zinc (not the iron) loses electrons and corrodes. Tin-plating gives no such back-up — because tin is *less* reactive than iron, a scratch in tin-plating actually makes the iron corrode *faster* than if it had no coating at all, since the more reactive iron becomes the anode against the tin.

VN **GIẢI THÍCH TIẾNG VIỆT**

Mạ kẽm (galvanising) khác với **mạ thiếc (tin-plating)**: kẽm hoạt động mạnh hơn sắt nên dù lớp mạ bị trầy, kẽm vẫn ăn mòn thay cho sắt (bảo vệ hy sinh — sacrificial protection). Ngược lại, thiếc kém hoạt động hơn sắt, nên nếu lớp mạ thiếc bị trầy, sắt bên dưới sẽ gỉ **nhanh hơn** bình thường vì đóng vai trò cực dương so với thiếc.

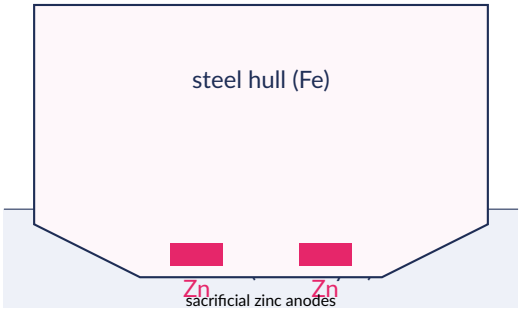
Ví dụ 11 · Sacrificial protection on a ship's hull

Blocks of zinc are bolted to the steel hull of a cargo ship, below the waterline. Explain, in terms of the reactivity series, how this protects the ship, and name the method.

This is **sacrificial protection**. Zinc is more reactive than iron (the main component of steel), so when both are in contact with seawater (an electrolyte), zinc loses electrons in preference to iron:

$$Zn -> Zn^{2+} + 2e^{-}$$

The electrons released flow into the steel hull, effectively supplying iron atoms with the electrons that would otherwise be lost during corrosion, so iron is protected from oxidation. The zinc blocks are gradually eaten away ("sacrificed") over months to years and are inspected and bolted on afresh during dry-docking, while the steel hull itself remains intact.



Sacrificial zinc anodes bolted below the waterline: zinc corrodes in preference to the iron hull.

9.6.3 Recycling metals (Supplement)

Why recycle metals? (Supplement)

Extracting a metal from its ore always uses substantial energy (mining, transporting, crushing, and then reducing the ore or electrolysing it), consumes a finite mineral resource, and generates waste rock and, often, greenhouse gas emissions. Recycling scrap metal avoids the mining and ore-processing steps entirely, so it typically uses far less energy, conserves ore reserves for the future, and reduces landfill waste and habitat disruption from mining.

VN **GIẢI THÍCH TIẾNG VIỆT**

Tái chế kim loại giúp tiết kiệm năng lượng (vì bỏ qua các bước khai thác quặng, vận chuyển, nghiền, khử/điện phân), bảo tồn tài nguyên quặng hữu hạn, giảm rác thải và tác động môi trường từ khai khoáng. Đây là lý do kinh tế lẫn môi trường đều ủng hộ việc tái chế, đặc biệt với nhôm — kim loại tốn rất nhiều điện để sản xuất từ quặng.

Ví dụ 12 · Energy saved by recycling aluminium (Supplement) (Supplement)

Recycling aluminium typically requires only about 5% of the energy needed to extract the same mass of new aluminium from bauxite ore by electrolysis (the rest is saved because mining, purification, and electrolysis are all avoided). Suppose producing 1 tonne of aluminium from ore requires approximately 15000 kWh of electrical energy. Estimate the energy required to recycle 1 tonne of aluminium instead, and the energy saved.

Energy to recycle $= 5\%$ of 15000 kWh $= 0.05 \times 15000 = 750$ kWh.
Energy saved $= 15000 - 750 = 14250$ kWh per tonne (about 95% of the original energy demand).

This large saving is why aluminium recycling (drinks cans, foil) is especially worthwhile economically and environmentally, compared with recycling a metal that needed less energy to extract in the first place.

Ôn tập nhanh

Ôn tập nhanh: (1) Tính chất kim loại (dẫn điện/nhiệt, dẻo, dễ kéo sợi, nóng chảy cao, sáng bóng, phát âm vang) đều bắt nguồn từ liên kết kim loại (ion dương + biển electron tự do). (2) Dãy hoạt động: K–Na–Ca–Mg–Al–(C)–Zn–Fe–(H)–Cu–Ag–Au; carbon/hydro là mốc quyết định phương pháp tách và phản ứng với axit. (3) Phản ứng thế: kim loại mạnh hơn đẩy kim loại yếu hơn ra khỏi muối/oxit — luôn kiểm tra thứ tự trước khi viết phương trình. (4) Lò cao: ba phản ứng chính (đốt than cốc, tạo CO, khử quặng) + đá vôi tạo xỉ. Nhôm: điện phân Al_2O_3 nóng chảy trong criolit. (5) Hợp kim cứng hơn kim loại nguyên chất vì nguyên tử lạ làm méo lớp mạng, cản trượt. (6) Gỉ sét cần **cả** oxy và nước; mạ kẽm vừa là lớp chắn vừa bảo vệ hy sinh (khác mạ thiếc chỉ là lớp chắn); tái chế kim loại (đặc biệt nhôm) tiết kiệm năng lượng đáng kể.

Practice

Bài tập luyện tập

Which property of metals is explained by the delocalised electrons being free to absorb and re-emit light at the surface?

(A) High melting point
(B) Sonority
(C) Lustre
(D) Ductility

Lời giải chi tiết

Delocalised electrons reflecting light at the surface gives metals their shiny, lustrous appearance. **(C)**.

Bài tập luyện tập

Explain, in terms of structure and bonding, why metals are malleable.

Lời giải chi tiết

In a metal, the positive ions are arranged in regular layers surrounded by a "sea" of delocalised electrons that is non-directional. Under an applied force, the layers of ions can slide over one another; the mobile electrons simply redistribute themselves around the ions' new positions, so the metallic bond is not broken. Because the attraction is maintained throughout, the metal deforms (is hammered/rolled into shape) rather than shattering.

Bài tập luyện tập

Copper and aluminium are both used for electrical wiring. Explain why, in terms of structure.

Lời giải chi tiết

Both copper and aluminium have delocalised electrons that are free to move throughout the metallic lattice. When a voltage is applied, these mobile electrons carry electric charge through the wire, so both metals conduct electricity well and are suitable for wiring.

Bài tập luyện tập

Which of the following correctly states the reactivity order (most to least reactive)?

(A) Na, K, Ca, Mg
(B) K, Na, Ca, Mg
(C) Ca, K, Na, Mg
(D) Mg, Ca, Na, K

Lời giải chi tiết

The reactivity series begins K $>$ Na $>$ Ca $>$ Mg. **(B)**.

Bài tập luyện tập

Explain why carbon, although not a metal, is included as a reference point in the reactivity series.

Lời giải chi tiết

Carbon's position tells us which metal oxides can be reduced economically by carbon (or carbon monoxide) in a furnace. Metals below carbon in the series (e.g. zinc, iron) are less reactive than carbon, so carbon can remove the oxygen from their ores. Metals above carbon (e.g. potassium, sodium, calcium, magnesium, aluminium) are more reactive than carbon, so carbon cannot reduce their compounds — these metals must instead be extracted by electrolysis of the molten compound.

Bài tập luyện tập

Predict what is observed, with an equation, when magnesium ribbon is heated strongly in steam.

Lời giải chi tiết

Magnesium burns brightly in steam, forming a white solid (magnesium oxide) and releasing

hydrogen gas:

$$Mg + H_2O(steam) -> MgO + H_2$$

Bài tập luyện tập

A piece of aluminium foil is placed in cold water and appears not to react. Explain why, and state whether aluminium is truly unreactive.

Lời giải chi tiết

Aluminium instantly forms a thin, tough, continuous layer of aluminium oxide (Al_2O_3) on its surface, which protects the metal underneath from further reaction with water — this is passivation. Aluminium is not truly unreactive: it lies well above zinc and iron in the reactivity series, and reacts readily once its protective oxide layer is removed or broken (e.g. by acid).

Bài tập luyện tập

Predict, giving a reason and an equation (or stating "no reaction"), what happens when: (a) zinc is added to iron(II) sulfate solution, (b) silver is added to copper(II) sulfate solution.

Lời giải chi tiết

(a) Zinc is above iron in the reactivity series, so zinc displaces iron: $Zn + FeSO_4 -> ZnSO_4 + Fe$.
(b) Silver is below copper in the reactivity series, so silver cannot displace copper: no reaction occurs.

Bài tập luyện tập

Iron filings are added to copper(II) sulfate solution. State two observations.

Lời giải chi tiết

The blue colour of the solution fades (pale green iron(II) sulfate forms as Cu^{2+} is used up), and a reddish-brown deposit of copper metal forms on the surface of the iron filings.

Bài tập luyện tập

Explain why the thermite reaction is useful for welding railway tracks, referring to both the chemistry and the practical advantage.

Lời giải chi tiết

Aluminium, being more reactive than iron, displaces iron from iron(III) oxide: $2Al + Fe_2O_3 -> Al_2O_3 + 2Fe$. The reaction is so exothermic that it reaches roughly $2500\,^{\circ}C$, well above iron's melting point, so molten iron is produced directly. This molten iron can be run into a mould around a gap between two rail ends, fusing them into a single continuous joint on cooling. The practical advantage is that the reaction needs no external electricity supply, so track can be welded on-site out in the field.

Bài tập luyện tập

Metals P, Q and R are tested: P displaces Q from solution; R does not displace P; Q does not displace R. Deduce the reactivity order of P, Q and R (most to least reactive).

Lời giải chi tiết

"P displaces Q" means P $>$ Q. "R does not displace P" means P $>$ R (R is not more reactive than P). "Q does not displace R" is consistent with R $>$ Q. Combining all three: P $>$ R $>$ Q.

Bài tập luyện tập

Which metal is extracted from its ore by electrolysis, because it is too reactive to be reduced by carbon?

(A) Iron
(B) Zinc
(C) Aluminium
(D) Copper

Lời giải chi tiết

Aluminium lies above carbon in the reactivity series, so carbon cannot reduce Al_2O_3; electrolysis of the molten oxide (dissolved in cryolite) is used instead. **(C)**.

Bài tập luyện tập

Which metal is found in the Earth's crust in its native (uncombined) state, because it is so unreactive?

(A) Iron
(B) Gold
(C) Sodium
(D) Magnesium

Lời giải chi tiết

Gold is at the very bottom of the reactivity series and does not readily form compounds, so it is found as the native metal. **(B)**.

Bài tập luyện tập

State the raw materials fed into the top of a blast furnace, and the purpose of each.

Lời giải chi tiết

Iron ore (haematite, mainly Fe_2O_3) — the source of iron, reduced to the metal. **Coke** (carbon) — burnt to provide heat, and converted to carbon monoxide, the main reducing agent. **Limestone** ($CaCO_3$) — decomposes to calcium oxide, which reacts with acidic silica impurities to form slag, removing them from the iron.

Bài tập luyện tập

Write and balance the equation for the reduction of iron(III) oxide by carbon monoxide in the blast furnace, and name the type of reaction.

Lời giải chi tiết

$$Fe_2O_3 + 3CO -> 2Fe + 3CO_2$$

This is a **reduction** reaction (oxygen is removed from the iron(III) oxide); carbon monoxide is oxidised to carbon dioxide, so it acts as the reducing agent.

Bài tập luyện tập

Explain, with equations, how limestone removes sand (silica, SiO_2) impurities from iron ore in the blast furnace.

Lời giải chi tiết

Limestone decomposes on heating: $CaCO_3 -> CaO + CO_2$. The calcium oxide produced then reacts with the acidic silica impurity: $CaO + SiO_2 -> CaSiO_3$. Calcium silicate (slag) is molten and less dense than the molten iron, so it floats on top and can be tapped off separately, leaving the iron free of this impurity.

Bài tập luyện tập

Explain why aluminium cannot be extracted by heating its ore with carbon, and outline the method actually used.

Lời giải chi tiết

Aluminium is more reactive than carbon, so carbon cannot remove the oxygen from aluminium oxide (carbon cannot "out-compete" aluminium for the oxygen). Instead, purified aluminium oxide is dissolved in molten cryolite (which lowers the melting point from over $2000\,^\circ$Cto about $950\,^\circ$C) and the mixture is electrolysed: aluminium ions are reduced at the cathode ($Al^{3+} + 3e^- -> Al$) and oxide ions are oxidised at the anode ($2O^{2-} -> O_2 + 4e^-$), giving the overall equation $2Al_2O_3 -> 4Al + 3O_2$.

Bài tập luyện tập

State the extraction method appropriate for each of the following metals, giving a reason based on the reactivity series: (a) calcium, (b) zinc, (c) silver.

Lời giải chi tiết

(a) **Calcium** — above carbon in the series → electrolysis of molten calcium chloride.
(b) **Zinc** — below carbon, above hydrogen → reduction using carbon/carbon monoxide.
(c) **Silver** — far below hydrogen, very unreactive → found mostly native, or obtained as a by-product of extracting other metals.

Bài tập luyện tập

Explain, in terms of atomic structure, why alloys are generally harder than the pure metals they are made from.

Lời giải chi tiết

In a pure metal, all atoms are the same size and pack into regular layers that slide past each other relatively easily under stress. In an alloy, atoms of a different element (usually a different size) are mixed in among the original metal atoms, distorting the regular layered structure. This disrupts the smooth sliding ("slip") of layers over one another, so a greater force is needed to deform the alloy — making it harder and stronger than the pure metal.

Bài tập luyện tập

Match each alloy to its two (or more) main components: brass, bronze, stainless steel.

Lời giải chi tiết

Brass = copper + zinc. **Bronze** = copper + tin. **Stainless steel** = iron + chromium + nickel.

Bài tập luyện tập

Duralumin is used to build aircraft bodies rather than pure aluminium. Suggest why. **(Supplement)**

Lời giải chi tiết

Duralumin is an alloy of aluminium with a small amount of copper (plus small amounts of magnesium and manganese). The added atoms distort the regular layers of aluminium atoms, hindering slip and making duralumin considerably stronger and harder than pure aluminium, while remaining almost as low in density. This combination of high strength and low weight is exactly what is needed for aircraft structures, where both strength (safety, load-bearing) and low mass (fuel efficiency) matter.

Bài tập luyện tập

What two substances must both be present for iron to rust?

(A) Oxygen and carbon dioxide
(B) Oxygen and water
(C) Water and salt
(D) Carbon dioxide and water

Lời giải chi tiết

Rusting needs both **oxygen** and **water**; if either is absent, iron does not rust. **(B)**.

Bài tập luyện tập

Describe an experiment, using three test tubes, to show that both oxygen and water are needed for iron to rust, and state the expected result in each tube.

Lời giải chi tiết

Tube 1: an iron nail in dry air, sealed with anhydrous calcium chloride to remove any moisture — no rust (no water present). Tube 2: an iron nail in freshly boiled water (oxygen removed by boiling), with a layer of oil on top to stop air re-dissolving — no rust (no oxygen present). Tube 3: an iron nail in ordinary water, left open to the air — rusts, because both dissolved/atmo-

spheric oxygen and water are present together. Only tube 3 shows rusting, confirming both substances are required.

Bài tập luyện tập

Blocks of magnesium are bolted to a buried steel pipeline. Explain how this protects the pipeline, and name the method.

Lời giải chi tiết

This is **sacrificial protection**. Magnesium is more reactive than iron, so in the presence of moisture in the soil (acting as an electrolyte), magnesium loses electrons and corrodes in preference to the iron pipeline. The magnesium blocks are gradually used up and must be replaced periodically, while the steel pipeline itself is protected from rusting.

Bài tập luyện tập

Explain why a scratch in a tin-plated steel can causes the steel to rust faster than an unplated steel can, whereas a scratch in galvanised (zinc-plated) steel does not cause faster rusting.

Lời giải chi tiết

Tin is less reactive than iron. Once the tin coating is scratched, the exposed iron becomes the more reactive metal in contact with the less reactive tin, so the iron loses electrons preferentially and corrodes *faster* than it would with no coating at all. Zinc, however, is more reactive than iron, so even where the galvanised coating is scratched, zinc continues to lose electrons in preference to iron (sacrificial protection), so the iron underneath remains protected rather than rusting faster.

Bài tập luyện tập

Explain why stainless steel resists rusting without needing a separate coating.

Lời giải chi tiết

Stainless steel is an alloy of iron with chromium (and usually nickel). The chromium reacts with oxygen in the air to form a thin, tough layer of chromium(III) oxide on the surface. Unlike ordinary rust, this oxide layer adheres strongly and does not flake off; if scratched, it re-forms (self-healing), continuously protecting the iron underneath from further oxidation.

Bài tập luyện tập

Give two reasons, one economic and one environmental, why recycling aluminium is preferred over extracting new aluminium from ore. **(Supplement)**

Lời giải chi tiết

Economic: recycling uses only a small fraction (around 5%) of the energy needed to extract new aluminium by electrolysis, so it is much cheaper in electricity costs, and it avoids the cost of mining and transporting bauxite ore. **Environmental:** recycling avoids the habitat destruction and waste rock produced by bauxite mining, and — because far less electricity is used — produces much lower associated greenhouse gas emissions (where electricity is generated

from fossil fuels), while also conserving finite ore reserves for the future.

Bài tập luyện tập

Producing 2 tonnes of new aluminium from bauxite ore requires 30000 kWh of electrical energy. If recycling the same mass of aluminium needs only 5% of this energy, calculate the energy saved by recycling instead. **(Supplement)**

Lời giải chi tiết

Energy to recycle $= 5\%$ of 30000 kWh $= 0.05 \times 30000 = 1500$ kWh.
Energy saved $= 30000 - 1500 = 28500$ kWh — recycling saves about 28 500 kWh (95%) of the energy that would otherwise be needed to extract the same mass of new aluminium from ore.

Bài tập luyện tập

"Metals are extracted, used, and eventually disposed of, but they can also be recycled." Using ideas from this unit, explain two advantages recycling scrap steel (iron) has over extracting new iron from ore, even though iron's extraction (blast furnace) already uses relatively little electrical energy compared with aluminium. **(Supplement)**

Lời giải chi tiết

Even though the blast furnace itself does not require electrolysis (so recycling saves proportionally less electrical energy than for aluminium), recycling scrap steel still avoids the energy and cost of mining, transporting and processing fresh iron ore, coke and limestone, so overall energy and cost savings remain significant. Recycling also conserves finite iron ore reserves and reduces the volume of waste (scrap metal sent to landfill) and the environmental disturbance caused by mining new ore, independent of how much electrical energy the original extraction method requires.

Chemistry of the Environment

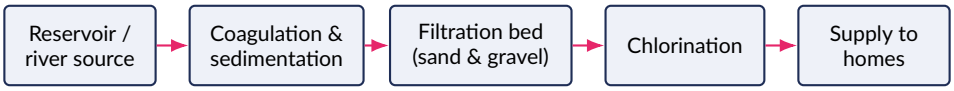
Mục tiêu Unit: Nguồn nước và quy trình xử lý nước sinh hoạt (keo tụ–lắng, lọc, khử trùng bằng clo); phân biệt phép thử cho biết nước **có mặt** với phép thử chứng minh nước **tinh khiết**; thành phần không khí sạch, khô; nguồn gốc, cơ chế và tác hại của các chất gây ô nhiễm không khí (CO, SO_2, NO_x, bụi mịn) và mưa axit; vai trò bộ chuyển đổi xúc tác trong ô tô; hiệu ứng nhà kính tự nhiên và hiệu ứng nhà kính tăng cường do con người, hậu quả biến đổi khí hậu; chu trình carbon đầy đủ; chu trình nitơ, phân bón NPK và cơ chế hiện tượng phú dưỡng (eutrophication).

10.1 Water

A reliable supply of clean, safe drinking water — **potable water** — is essential for human health. Water is drawn from two main types of source: **surface water** (rivers, lakes and reservoirs, replenished by rainfall runoff) and **groundwater** (water stored in permeable rock underground, reached by sinking wells or boreholes, and often naturally pre-filtered by the rock it has passed through). Whichever the source, raw water usually carries suspended solid particles (silt, clay), dissolved salts and minerals, and disease-causing microorganisms (pathogens), so it must be treated before it is safe to drink.

Stages of water treatment for a public supply (in order):

1. **Screening**: raw water passes through metal screens/grids that remove large floating debris (leaves, twigs, litter).
2. **Coagulation and sedimentation**: a coagulant chemical (e.g. aluminium sulfate) is stirred into the water; this makes the very fine suspended clay and silt particles clump together into larger, heavier clumps (*floc*), which then settle to the bottom of large sedimentation tanks under gravity and are removed as sludge.
3. **Filtration**: the water passes downward through a deep bed of sand and gravel, which traps the remaining fine suspended particles and much of the remaining bacteria by physically straining them out.
4. **Chlorination**: a small, carefully controlled dose of chlorine gas (or a chlorine-releasing compound) is added last, killing the disease-causing bacteria and viruses that filtration did not remove.



A simple water-treatment works: a coagulant clumps fine suspended particles together so they settle out by sedimentation; filtration through sand/gravel beds traps the remaining fine particles; a controlled chlorine dose kills disease-causing microorganisms immediately before the water reaches the supply network.

VN **GIẢI THÍCH TIẾNG VIỆT**

Nước sinh hoạt được xử lý qua các bước: **sàng lọc thô** (loại rác lớn), **keo tụ–lắng** (hoá chất keo tụ làm hạt mịn kết dính thành cụm lớn rồi lắng xuống nhờ trọng lực), **lọc** (qua lớp cát/sỏi giữ

lại hạt mịn còn sót), và **khử trùng bằng clo** (liều lượng nhỏ, được thêm *sau cùng*, tiêu diệt vi khuẩn/virus gây bệnh còn sót lại). Thứ tự các bước không phải ngẫu nhiên — mỗi bước xử lý một loại tạp chất khác nhau, và bước sau phụ thuộc vào bước trước đã hoàn thành.

Chlorine disinfects the water because, even at a very low, carefully-controlled concentration, it damages the proteins in the cell walls of bacteria and destroys the protein coats of viruses, killing or inactivating them — while the tiny dose used is far too small to harm the much larger cells of the human body. Chlorination does *not* remove dissolved salts or other dissolved substances, so it cannot by itself produce very pure water for laboratory or industrial use; that requires a further purification step such as distillation.

Ví dụ mẫu · Why does the order of treatment steps matter?

Explain why sedimentation must occur *before* filtration, and why chlorination must be the *last* step, rather than any other order.

Sedimentation before filtration: raw water can carry a very large mass of suspended solids. If this water were sent straight to the sand filter, the filter bed would clog (block) almost immediately and would need constant, costly cleaning or replacement. Sedimentation removes the great majority of suspended solids cheaply, using gravity alone, so the filter bed only has to deal with the small quantity of fine particles that remain — it lasts far longer and works far more effectively.

Chlorination last: suspended solid particles and organic debris can physically shield microorganisms from contact with the chlorine, and can also react with (consume) the chlorine dose before it reaches the pathogens, wasting the chemical. By removing solids first (sedimentation and filtration), the water reaching the chlorination stage is already clear, so the small, carefully measured chlorine dose acts efficiently and reliably on the remaining microorganisms rather than being used up by dirt.

10.1.1 Testing water: presence versus purity

It is essential to distinguish two very different questions: "does this sample contain water?" and "is this sample *pure* water?".

Tests that only show water is *present* (chemical spot tests):

- **Anhydrous copper(II) sulfate**: a white powder turns **blue** when water is added: $CuSO_4 + 5H_2O -> CuSO_4 \cdot 5H_2O$.
- **Cobalt(II) chloride paper**: blue paper turns **pink** when water is added.

Both tests change colour with even a few drops of water mixed into *any* other liquid or solution — they cannot tell pure water apart from a solution that merely contains water.

The test that shows water is *pure* — physical properties:

- **Melting point**: pure water freezes/melts sharply at exactly $0\,^{\circ}\text{C}$ at standard atmospheric pressure. Any dissolved solute lowers this value and causes melting to occur gradually over a *range* of temperature rather than at one sharp point.
- **Boiling point**: pure water boils sharply at exactly $100\,^{\circ}\text{C}$ at standard atmospheric pressure. Any dissolved solute raises this value and again causes boiling to occur over a *range* rather than at one fixed temperature. Because it is quick, quantitative and directly comparable to a known reference value, this is regarded as the **most reliable single test of purity**.

(!) Lỗi thường gặp: Anhydrous $CuSO_4$ turning blue, or cobalt chloride paper turning pink, only proves that water is *present* in a sample — it says *nothing* about whether that water is pure. To test purity, you must measure the melting point or boiling point and compare it against the sharp, known reference value for pure water ($0\,^\circ$C and $100\,^\circ$C respectively at standard atmospheric pressure): a sharp match proves purity, while a broadened range at a shifted temperature proves the sample is impure.

Ví dụ mẫu · An unknown colourless liquid

A technician is given an unlabelled, colourless liquid and must decide whether it is pure water. Two tests are carried out: (i) a few drops of the liquid are added to white anhydrous copper(II) sulfate powder, which turns blue; (ii) the liquid is heated and its temperature is monitored continuously as it boils, remaining constant at exactly $100\,^\circ$C throughout boiling (measured at standard atmospheric pressure). What can be concluded from each test, and what further test would make the conclusion even more certain?

Test (i): the colour change from white to blue shows only that the liquid *contains water* — it could equally well be pure water or a dilute solution, since even a small amount of dissolved water in another liquid would give the same result.

Test (ii): a boiling point of exactly $100\,^\circ$C that stays constant (does not drift upward as boiling proceeds) matches the accepted value for pure water very closely, providing strong evidence of purity — an impure sample would boil at a higher temperature and the temperature would tend to creep upward as the more concentrated solution left behind boils at an increasingly higher temperature.

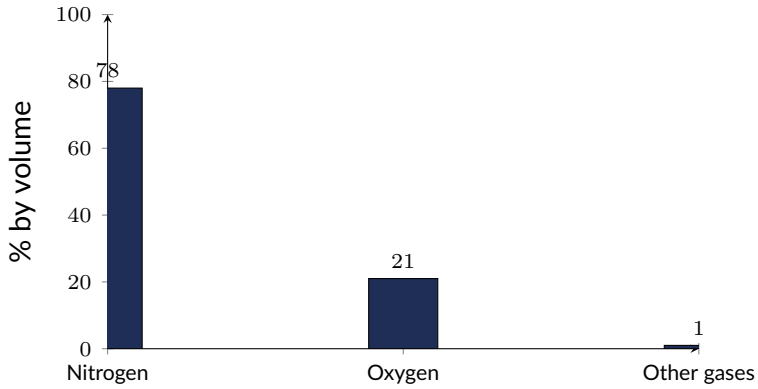
Further test: to be fully confident, also measure the **melting/freezing point** of a small sample and check it is exactly $0\,^\circ$C. Because both the melting point *and* the boiling point of pure water are precisely known, a substance that matches *both* values sharply is confirmed to be pure water; matching only one value is good evidence but checking both removes any remaining doubt.

10.2 Composition of clean, dry air

Clean, dry air is a mixture of gases in an approximately fixed proportion, with two exceptions that vary from place to place and moment to moment.

Approximate composition of clean, dry air by volume:

- **Nitrogen,** N_2 — about **78%**.
- **Oxygen,** O_2 — about **21%**.
- **Other gases** — about **1%**, of which almost all is the noble (inert) gas **argon**, Ar ($\approx 0.9\%$), with only trace amounts of neon, helium and other noble gases.
- **Carbon dioxide,** CO_2, present at a low, slowly-rising concentration (roughly 0.04% by volume in recent years).
- **Water vapour** — highly **variable**, from almost none over a hot desert to several percent in humid tropical air; it is excluded when air is described as "dry".



Approximate composition of clean, dry air by volume: about 78% nitrogen, 21% oxygen and 1% other gases (almost entirely argon), with variable, separately-counted carbon dioxide and water vapour.

VN **GIẢI THÍCH TIẾNG VIỆT**

Không khí sạch, khô gồm khoảng **78% nitơ**, **21% oxi**, và ≈**1%** khí khác (chủ yếu là khí trơ **argon**). Carbon dioxide chiếm tỉ lệ nhỏ, đang tăng chậm theo thời gian; hơi nước có tỉ lệ **thay đổi** rất nhiều tuỳ nơi và tuỳ thời điểm — đó là lý do định nghĩa thành phần trên áp dụng cho không khí "khô".

10.3 Air pollutants: sources, effects and control

Burning fuels — in power stations, factories and vehicle engines — releases several substances that are not natural components of clean air and that damage health or the environment.

10.3.1 Carbon monoxide

Carbon monoxide, CO, forms when a carbon-based fuel undergoes **incomplete combustion** — burning in a limited supply of oxygen:

$$2C + O_2 \rightarrow 2CO \qquad (\text{incomplete combustion, compare with } C + O_2 \rightarrow CO_2 \text{ when oxygen is plentiful}).$$

Carbon monoxide is **colourless** and **odourless**, so a build-up cannot be detected by sight or smell, yet it is highly toxic: it binds to the haemoglobin in red blood cells much more strongly (and far less reversibly) than oxygen does, forming **carboxyhaemoglobin**. Haemoglobin molecules locked up in this way can no longer carry oxygen, so the blood's oxygen-carrying capacity falls; body tissues — including the brain and heart — are starved of oxygen, which can cause headaches, unconsciousness and death even at fairly low atmospheric concentrations.

10.3.2 Sulfur dioxide and nitrogen oxides

Sulfur dioxide, SO_2, forms when a fuel containing sulfur impurities (most notably coal, and some crude-oil fractions) is burned:

$$S + O_2 \rightarrow SO_2.$$

Nitrogen oxides, NO_x, are *not* present in the original fuel at all — they form when nitrogen and oxygen from the air itself react together, driven by the very high temperatures reached inside a vehicle engine cylinder or a furnace (a reaction that does not occur to any significant extent at ordinary atmospheric temperatures):

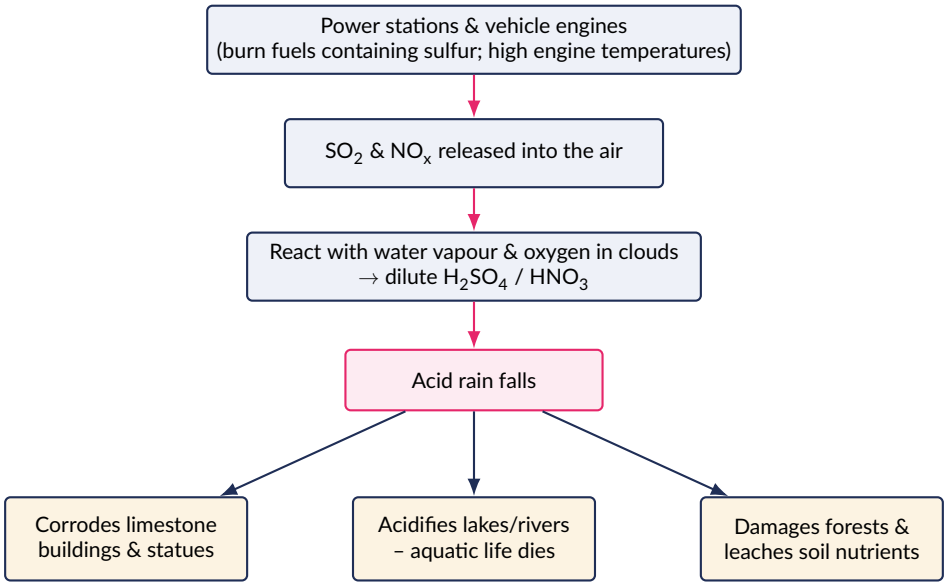
$$N_2 + O_2 \rightarrow 2NO\,, \qquad 2NO + O_2 \rightarrow 2NO_2.$$

Acid rain: both SO_2 and NO_x dissolve in droplets of atmospheric moisture and are further oxidised (helped by sunlight and trace substances in clouds) into **sulfuric acid** and **nitric acid**, which fall as **acid rain**:

$$SO_2 \to \cdots \to H_2SO_4\,, \qquad NO_2 \to \cdots \to HNO_3.$$

Effects of acid rain:

- Corrodes buildings and statues made of limestone/marble (calcium carbonate): $CaCO_3 + H_2SO_4 -> CaSO_4 + H_2O + CO_2$.
- Lowers the pH of lakes and rivers, killing fish, insects and other aquatic organisms (fish eggs and young fish are especially sensitive).
- Damages forests: acid directly damages leaves, and it also leaches essential nutrient ions (e.g. Mg^{2+}, Ca^{2+}) out of the soil while releasing toxic aluminium ions that damage tree roots.
- Corrodes exposed metal structures (e.g. iron and steel).



Formation and effects of acid rain: SO_2 and NO_x from combustion dissolve in atmospheric moisture and oxidise to sulfuric and nitric acid, which then damage limestone structures, freshwater ecosystems and forests.

10.3.3 Particulates (soot)

Unburnt carbon particles and partially-burnt hydrocarbons, together called **particulates** or soot, are released by incomplete combustion. Breathed in, fine particulates irritate and damage the lungs, aggravating conditions such as asthma and bronchitis. In large quantities in the atmosphere, particulates also scatter and reflect incoming sunlight, measurably reducing the solar radiation reaching the Earth's surface — an effect known as **global dimming**.

Pollutant	Main source	Main effect(s)
Carbon monoxide, CO	Incomplete combustion of carbon-based fuels	Binds haemoglobin; reduces blood's oxygen-carrying capacity
Sulfur dioxide, SO_2	Combustion of fuels containing sulfur impurities (esp. coal)	Dissolves in moisture → acid rain
Nitrogen oxides, NO_x	$N_2 + O_2$ reacting at high engine/furnace temperature	Dissolves in moisture → acid rain
Particulates (soot)	Incomplete combustion of carbon-based fuels	Respiratory illness; global dimming

VN **GIẢI THÍCH TIẾNG VIỆT**

CO sinh ra khi đốt cháy *không hoàn toàn* (thiếu oxi), gắn chặt vào hemoglobin làm giảm khả năng vận chuyển oxi của máu — độc, không màu, không mùi. SO_2 sinh ra từ lưu huỳnh lẫn trong nhiên liệu (đặc biệt than đá); NO_x sinh ra khi N_2 và O_2 trong không khí phản ứng ở nhiệt độ cao trong động cơ. Cả hai hoà tan vào hơi ẩm khí quyển, bị oxi hoá thành H_2SO_4/HNO_3 → **mưa axit**: ăn mòn công trình đá vôi, hạ pH sông hồ giết sinh vật thuỷ sinh, và gây hại rừng cây. **Bụi mịn** (carbon chưa cháy hết) gây bệnh hô hấp và góp phần làm mờ ánh sáng mặt trời (global dimming).

Ví dụ mẫu · Mass of CO_2 from burning pure carbon

Calculate the mass of carbon dioxide produced when 120 kg of pure carbon (from coal) undergoes complete combustion: $C + O_2 -> CO_2$.

moles C $= \dfrac{120\,000}{12} = 10\,000$ mol. Mole ratio C : $CO_2 = 1:1$, so moles $CO_2 = 10\,000$ mol.

$$\text{mass}(CO_2) = 10\,000 \times 44 = 440\,000 \text{ g} = 440 \text{ kg}.$$

Ví dụ mẫu · Mass of CO_2 from burning methane

Complete combustion of methane in a power station follows $CH_4 + 2O_2 -> CO_2 + 2H_2O$. Calculate the mass of CO_2 produced from burning 80 kg of methane.

moles $CH_4 = \dfrac{80\,000}{16} = 5000$ mol = moles CO_2 (mole ratio 1:1).

$$\text{mass}(CO_2) = 5000 \times 44 = 220\,000 \text{ g} = 220 \text{ kg}.$$

Ví dụ mẫu · Volume of CO_2 from burning butane

Butane, C_4H_{10} ($M_r = 58$), is the fuel in a camping-gas canister: $2C_4H_{10} + 13O_2 -> 8CO_2 + 10H_2O$. Calculate the volume of CO_2, at r.t.p., produced by completely burning 5.8 g of butane.

moles $C_4H_{10} = \dfrac{5.8}{58} = 0.1$ mol. Mole ratio $C_4H_{10} : CO_2 = 2 : 8 = 1 : 4$, so moles $CO_2 = 0.1 \times 4 = 0.4$ mol.

$$V(CO_2) = 0.4 \times 24 = 9.6 \text{ dm}^3 \ (9600 \text{ cm}^3) \text{ at r.t.p.}$$

Ví dụ mẫu · Mass and volume of SO_2 from sulfur-contaminated diesel

A power station burns 40000 kg (4.0×10^7 g) of diesel fuel per day. The fuel contains 0.5% sulfur by mass, which burns completely: $S + O_2 -> SO_2$. Calculate (a) the mass, and (b) the volume at r.t.p., of sulfur dioxide released per day.

(a) Mass: mass of sulfur $= 4.0 \times 10^7 \times 0.005 = 2.0 \times 10^5$ g.

moles S $= \dfrac{2.0 \times 10^5}{32} = 6250$ mol. Mole ratio S : $SO_2 = 1:1$, so moles $SO_2 = 6250$ mol.

$$\text{mass}(SO_2) = 6250 \times 64 = 400\,000 \text{ g} = 400 \text{ kg per day.}$$

(b) Volume at r.t.p.:

$$V(SO_2) = 6250 \times 24 = 150\,000 \text{ dm}^3 = 150 \text{ m}^3 \text{ per day.}$$

(!) Lỗi thường gặp: Do not confuse the gases that cause **acid rain** (SO_2 and NO_x, which dissolve in atmospheric moisture to form acids) with the **greenhouse gases** (CO_2, CH_4, water vapour, which absorb and re-emit infrared radiation). Although some of these gases come from the very same combustion processes, they act through completely different chemical mechanisms and cause completely different environmental problems — acid rain is a local/regional acidity problem, while the enhanced greenhouse effect is a global warming problem.

10.3.4 Catalytic converters (Supplement)

Modern vehicles are fitted with a **catalytic converter** in the exhaust system: a ceramic honeycomb structure coated with a thin layer of **platinum** and **rhodium**. As hot exhaust gases pass over the huge surface area of this coating, toxic carbon monoxide and nitrogen monoxide react together and are converted into far less harmful products:

$$2CO + 2NO \rightarrow 2CO_2 + N_2.$$

Unburnt hydrocarbons in the exhaust are simultaneously oxidised to carbon dioxide and water on the same catalyst surface. The platinum and rhodium act as a **catalyst**: exhaust gas molecules adsorb onto the metal surface, which weakens their existing bonds and holds the reacting molecules close together in a favourable orientation, providing an alternative reaction pathway with a lower activation energy. This speeds up the conversion enormously without the precious metal itself being used up or permanently changed by the reaction.

Ví dụ mẫu · Catalytic converter equation

(Supplement) Balance the equation for the reaction between carbon monoxide and nitrogen monoxide inside a catalytic converter, and explain the role of the platinum/rhodium catalyst.

Balancing: start from $CO + NO -> CO_2 + N_2$. Nitrogen atoms are odd on the left (1 per NO) but must pair up as N_2 on the right, so at least two NO are needed; matching the carbon and oxygen atoms then requires two CO and two CO_2:

$$2CO + 2NO \rightarrow 2CO_2 + N_2.$$

Check: left — C: 2, O: $2 + 2 = 4$, N: 2. Right — C: 2, O: $2 \times 2 = 4$, N: 2. Balanced.

Role of the catalyst: platinum and rhodium provide a solid surface on which CO and NO molecules can adsorb; this weakens the bonds within them and lowers the activation energy needed for the reaction, so the toxic gases are converted into carbon dioxide and nitrogen far

more quickly than they would react on their own. The metals themselves take part in the surface reaction but are regenerated at the end, so they are not consumed and remain available to catalyse further reactant molecules continuously.

VN **GIẢI THÍCH TIẾNG VIỆT**

Bộ chuyển đổi xúc tác trong ống xả ô tô có lớp phủ **bạch kim (Pt)** và **rhodi (Rh)**, biến khí CO và NO độc hại thành CO_2 và N_2 ít hại hơn: $2CO + 2NO \rightarrow 2CO_2 + N_2$. Kim loại quý đóng vai trò **xúc tác**: khí hấp phụ lên bề mặt kim loại, làm yếu liên kết cũ, hạ năng lượng hoạt hoá, tăng tốc phản ứng — nhưng bản thân kim loại không bị tiêu hao.

10.4 The greenhouse effect and climate change

The Earth's surface is warmed by short-wavelength radiation from the Sun, which passes through the atmosphere largely unabsorbed. The warmed surface re-emits this energy as longer-wavelength **infrared radiation**. **Greenhouse gases** — principally carbon dioxide, methane and water vapour — absorb this outgoing infrared radiation and re-emit it in all directions, including back down towards the surface. This natural **greenhouse effect** keeps the Earth's average surface temperature far higher than it would otherwise be, and is essential for supporting life as we know it.

The enhanced greenhouse effect: human activities have significantly increased the atmospheric concentration of greenhouse gases, intensifying the natural greenhouse effect beyond its usual level:

- **Burning fossil fuels** (coal, oil, natural gas) for electricity, transport and industry releases extra carbon dioxide that had been locked away for millions of years.
- **Deforestation** removes trees that would otherwise absorb CO_2 by photosynthesis, and burning cleared vegetation releases stored carbon directly.
- **Livestock farming** — cattle and other ruminants produce methane during digestion (enteric fermentation); rice paddy cultivation is a further methane source.
- **Decomposition of waste in landfill sites**, often under anaerobic (low-oxygen) conditions, produces methane as organic matter breaks down.

Consequences: global warming (rising average global temperatures); **rising sea levels**, caused both by the thermal expansion of warming seawater and by melting land-based ice (glaciers and ice sheets); and broader **climate change**, including shifting rainfall patterns and more frequent extreme weather events.

(!) Lỗi thường gặp: Do not confuse the (natural) **greenhouse effect** — the normal, essential warming that keeps the Earth habitable — with the **enhanced greenhouse effect**, the additional, human-caused warming from extra greenhouse gases released by burning fossil fuels, deforestation, livestock farming and landfill waste. The greenhouse effect itself is not the problem; the human-caused *increase* in it is.

VN **GIẢI THÍCH TIẾNG VIỆT**

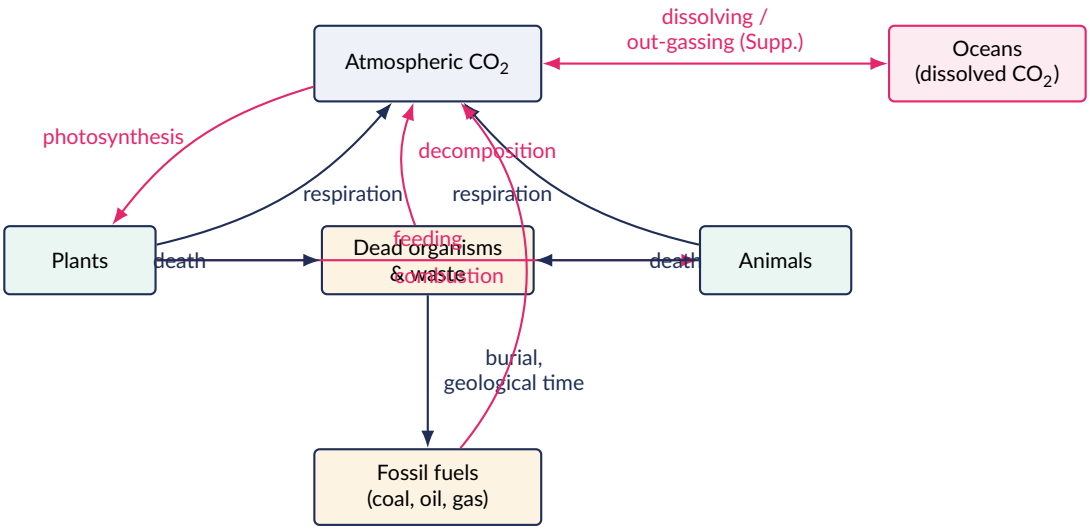
Bức xạ mặt trời (sóng ngắn) xuyên qua khí quyển làm nóng bề mặt Trái Đất; bề mặt phát lại bức xạ hồng ngoại (sóng dài), bị khí nhà kính (CO_2, CH_4, hơi nước) hấp thụ và phát lại — giữ ấm khí quyển một cách **tự nhiên và cần thiết**. Hoạt động con người (đốt nhiên liệu hoá thạch, phá rừng, chăn nuôi, bãi rác) làm **tăng thêm** nồng độ khí nhà kính → **hiệu ứng nhà kính tăng**

cường → Trái Đất nóng lên, mực nước biển dâng (giãn nở nhiệt của nước biển + băng tan), thời tiết cực đoan gia tăng.

10.5 The carbon cycle

Carbon is continuously exchanged between the atmosphere, living organisms, and long-term storage, in a self-balancing sequence called the **carbon cycle**.

- **Photosynthesis** removes CO_2 from the atmosphere, using light energy to build carbohydrates in plants: $6CO_2 + 6H_2O -> C_6H_{12}O_6 + 6O_2$. This carbon then passes along food chains as animals eat plants (and other animals).
- **Respiration**, in both plants and animals, continuously returns CO_2 to the atmosphere: $C_6H_{12}O_6 + 6O_2 -> 6CO_2 + 6H_2O$.
- **Combustion** of wood or fossil fuels returns carbon to the atmosphere rapidly, as CO_2.
- **Decay**: microorganisms and other decomposers break down dead organisms and waste; aerobic decay releases CO_2 (anaerobic decay, in the absence of oxygen, instead releases methane).
- **Fossil fuel formation**: over millions of years (geological time), the remains of dead plants and animals that did not fully decompose — for example, buried under sediment or in oxygen-poor swamps and seas — were subjected to high pressure and temperature and slowly converted into coal, oil and natural gas, locking their carbon away from the atmosphere for a very long time. Burning fossil fuels releases this long-stored carbon far more quickly than it took to form, which is why it disturbs the natural balance of the cycle.



The carbon cycle: photosynthesis removes CO_2 from the atmosphere into plants; carbon passes to animals by feeding; respiration, decomposition and combustion return CO_2 to the atmosphere; some dead matter is buried and slowly converted into fossil fuels over geological time; the oceans continuously exchange dissolved CO_2 with the atmosphere.

10.5.1 Ocean–atmosphere exchange of carbon dioxide (Supplement)

The oceans act as an enormous reservoir, or **carbon sink**, for atmospheric CO_2. Carbon dioxide continually dissolves into the ocean surface (helped further by photosynthesis in marine phytoplankton) and is also released back into the atmosphere, with the balance between the two directions depending on temperature and on the relative concentration of CO_2 in the air and in the water. Because **cooler water can dissolve more gas than warmer water**, a warming ocean both absorbs

atmospheric CO_2 less effectively and tends to release some of the CO_2 it already holds, which can amplify the rise in atmospheric CO_2. Dissolved CO_2 also reacts with water to form a weak acid ($CO_2 + H_2O -> H_2CO_3$), gradually lowering the average pH of the oceans (**ocean acidification**) — a growing threat to marine organisms such as corals and shelled plankton that build their skeletons or shells from calcium carbonate, which dissolves more readily as the water becomes more acidic.

VN **GIẢI THÍCH TIẾNG VIỆT**

Quang hợp **lấy** CO_2 khỏi khí quyển vào thực vật; carbon truyền sang động vật qua chuỗi thức ăn; hô hấp, phân huỷ và đốt cháy **trả lại** CO_2. Một phần xác sinh vật bị chôn vùi, qua hàng triệu năm biến thành nhiên liệu hoá thạch (than, dầu, khí) — đốt cháy giải phóng carbon đó nhanh hơn nhiều so với thời gian nó được lưu trữ. (Supplement) Đại dương liên tục trao đổi CO_2 hoà tan với khí quyển; đại dương ấm lên hấp thụ CO_2 kém hơn và có thể giải phóng bớt CO_2 đã hoà tan, đồng thời CO_2 hoà tan làm nước biển bị axit hoá dần, đe doạ sinh vật có vỏ/xương làm từ calcium carbonate.

10.6 The nitrogen cycle and fertilisers

Nitrogen gas, N_2, makes up about 78% of the atmosphere, but the triple covalent bond joining the two nitrogen atoms is extremely strong, making N_2 very unreactive. Most living organisms cannot use atmospheric N_2 directly — it must first be **fixed**: converted into more reactive nitrogen compounds that plants can absorb.

Natural nitrogen fixation:

- **Lightning**: the enormous energy released by a lightning strike forces N_2 and O_2 in the air to react, forming nitrogen oxides that dissolve in rain and reach the soil as dilute nitrates.
- **Nitrogen-fixing bacteria**: some bacteria live freely in soil, while others live symbiotically in root nodules of leguminous plants (peas, beans, clover); both convert atmospheric N_2 directly into ammonium/nitrogen compounds usable by plants (the legume supplies the bacteria with carbohydrates in return).

Industrial nitrogen fixation: ammonia is manufactured on a huge scale by the **Haber process**, $N_2 + 3H_2 \rightleftharpoons 2NH_3$ (covered in detail in the chapter on ammonia and industrial chemistry), and converted into nitrate/ammonium fertilisers.

Plants absorb nitrogen mainly as **nitrate ions**, NO_3^-, dissolved in soil water and taken up through their roots, using it to build amino acids, proteins, nucleic acids and chlorophyll. This nitrogen then passes to animals, as protein, when they eat plants (and further along food chains).

10.6.1 Nitrification and denitrification (Supplement)

(Supplement) **Decay (ammonification)**: decomposer microorganisms break down proteins and nitrogen-containing waste (e.g. urea, faeces) from dead organisms, releasing **ammonium** compounds back into the soil.

(Supplement) **Nitrification**: nitrifying bacteria in the soil oxidise these ammonium compounds in two stages, first to nitrite and then to nitrate: $NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$, making nitrogen available for plant roots to absorb again.

(Supplement) **Denitrification**: in waterlogged, oxygen-poor soil, denitrifying bacteria convert soil nitrates back into atmospheric N_2 gas, completing the cycle back to the atmosphere.

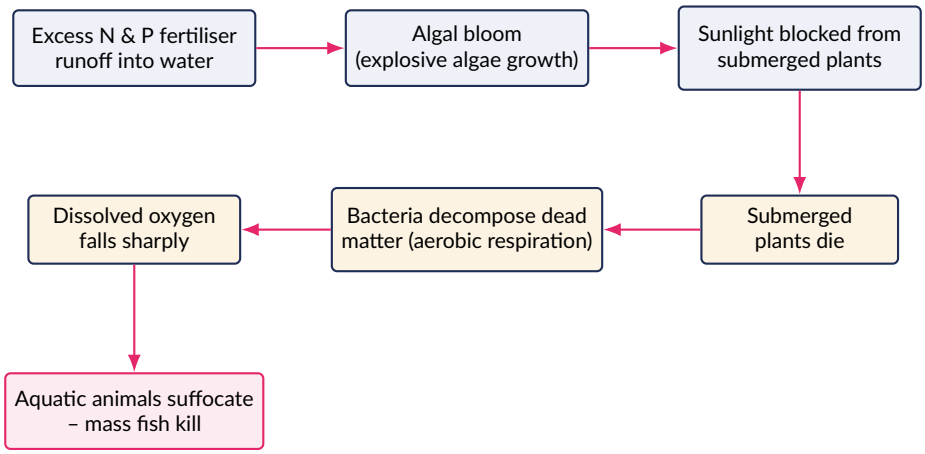
NPK fertilisers are manufactured to supply the three nutrients plants need in the largest quantities, in a concentrated and immediately available form:

- **Nitrogen (N)** — for making amino acids, proteins and chlorophyll; promotes healthy leaf and stem growth.
- **Phosphorus (P)** — for root development and for seed/fruit formation (and for energy-transfer compounds within the plant).
- **Potassium (K)** — for enzyme activation and for healthy flowering, fruiting and disease resistance.

Applying *far more* fertiliser than a crop can absorb does not increase yield further; the surplus nitrate and phosphate is easily washed (leached) by rainfall off the field and into nearby streams, rivers and lakes, causing **eutrophication**.

Eutrophication — the full mechanism:

1. Excess nitrate and phosphate fertiliser is washed by rain off farmland into a river or lake, sharply raising the concentration of nutrients that are normally scarce.
2. Algae and other aquatic plants, no longer limited by a shortage of nutrients, multiply explosively — an **algal bloom** covers the water's surface.
3. The dense surface layer of algae blocks sunlight from reaching plants growing deeper in the water.
4. Deprived of light, these submerged plants can no longer photosynthesise, and they die.
5. Bacteria decomposing the large mass of dead plant and algal matter respire aerobically, consuming the dissolved oxygen in the water far faster than it can be replenished.
6. The dissolved oxygen concentration falls below the level fish and other aquatic animals need to survive, and they **suffocate** — a mass fish kill results, and the ecosystem collapses.



Eutrophication: excess fertiliser runoff triggers an algal bloom that blocks light, killing submerged plants; bacterial decomposition of the dead matter consumes dissolved oxygen, suffocating aquatic animals.

VN **GIẢI THÍCH TIẾNG VIỆT**

N_2 trong khí quyển rất trơ (liên kết ba bền); phải được "**cố định**" thành hợp chất nitơ hữu ích nhờ sấm sét, vi khuẩn cố định đạm (tự do hoặc trong nốt sần rễ cây họ đậu), hoặc công nghiệp (quy trình Haber: $N_2 + 3H_2 \rightleftharpoons 2NH_3$). **(Supplement)** Vi khuẩn nitrat hoá oxi hoá $NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$; vi khuẩn khử nitrat (trong đất ngập nước, thiếu oxi) trả NO_3^- về lại N_2. Phân bón NPK

cung cấp N (lá/thân), P (rễ/hạt), K (hoa/quả/kháng bệnh). Bón **dư thừa** bị rửa trôi xuống sông hồ → **phú dưỡng**: tảo nở hoa → chặn ánh sáng → thực vật chìm chết → vi khuẩn phân huỷ tiêu thụ hết oxi hoà tan → cá và sinh vật thuỷ sinh chết ngạt hàng loạt.

Ví dụ mẫu · Eutrophication in a farm pond

A pond next to a farm receives heavy runoff of phosphate and nitrate fertiliser after a storm. Describe, in sequence, what happens to the pond ecosystem over the following weeks, referring explicitly to dissolved oxygen.

Step 1: the surplus nitrate and phosphate dissolve into the pond, sharply raising the concentration of nutrients that are normally in short supply, removing the limit on algal growth.
Step 2: algae and floating aquatic plants multiply explosively, forming a dense **algal bloom** across the water's surface.
Step 3: the algal layer blocks sunlight from reaching plants rooted deeper in the pond; unable to photosynthesise, these submerged plants die.
Step 4: bacteria that decompose the large mass of dead algae and plant matter respire aerobically, consuming dissolved oxygen from the water much faster than photosynthesis or diffusion from the air can replace it.
Step 5: the dissolved oxygen concentration falls below the level fish and other aquatic animals need; they **suffocate** and die in large numbers, and the water may begin to smell as anaerobic decomposition takes over once oxygen is exhausted.

Ví dụ mẫu · Haber process stoichiometry (cross-reference) (Supplement)

Using $N_2 + 3H_2 \rightleftharpoons 2NH_3$, calculate the mass of ammonia that could in principle be produced from 28 kg of nitrogen gas, assuming complete conversion.

moles $N_2 = \dfrac{28\,000}{28} = 1000$ mol. Mole ratio $N_2 : NH_3 = 1 : 2$, so moles $NH_3 = 2000$ mol.

$$\text{mass}(NH_3) = 2000 \times 17 = 34\,000\ \text{g} = 34\ \text{kg}.$$

(In practice, because the Haber process is a reversible reaction reaching equilibrium rather than going to completion, the actual yield obtained is less than this theoretical maximum.)

10.7 Practice

Bài tập luyện tập

Which stage of water treatment removes suspended solid particles mainly by allowing them to settle under gravity, after a coagulant has clumped fine particles together?

(A) Chlorination
(B) Coagulation and sedimentation
(C) Screening
(D) Distillation

Lời giải chi tiết

Coagulation and sedimentation: a coagulant makes fine suspended particles clump into larger floc, which then settles under gravity in large tanks, before filtration and chlorination. **(B)**.

Bài tập luyện tập

Explain why the concentration of chlorine used to disinfect drinking water is safe for people to drink but lethal to bacteria and viruses.

Lời giải chi tiết

The chlorine dose used is carefully controlled to be just large enough to destroy the proteins in the cell walls/coats of microorganisms and kill or inactivate them, while being far too dilute to cause significant harm to the much larger cells of the human body. It is a difference of concentration and dose, not a difference in the underlying chemistry.

Bài tập luyện tập

A student adds anhydrous copper(II) sulfate to a colourless liquid and it turns blue. Which conclusion is correctly supported?

(A) The liquid is pure water
(B) The liquid contains water, but may not be pure
(C) The liquid contains no water
(D) The liquid is definitely a solution, not pure water

Lời giải chi tiết

Anhydrous $CuSO_4$ only detects the *presence* of water; it cannot distinguish pure water from a solution containing water. **(B)**.

Bài tập luyện tập

A water sample is boiled and its temperature recorded continuously; boiling occurs gradually over the range $100\,^{\circ}$C to $103\,^{\circ}$C. What does this indicate about the sample?

Lời giải chi tiết

Pure water boils sharply at exactly $100\,^{\circ}$C at standard atmospheric pressure. Boiling over a *range*, above the pure value, shows that the sample is **impure** — it contains dissolved substances (a solution), which raise and broaden the boiling point.

Bài tập luyện tập

Which single statement best distinguishes surface water from groundwater as a drinking-water source?

(A) Surface water always needs no treatment; groundwater always does
(B) Surface water is collected from rivers/lakes/reservoirs; groundwater is drawn from wells/boreholes into permeable rock
(C) Groundwater is always saltwater
(D) Surface water cannot be chlorinated

Lời giải chi tiết

(B): surface water comes from above-ground bodies fed by rainfall runoff, while groundwater is stored underground in permeable rock and reached via wells/boreholes (often naturally pre-filtered).

Bài tập luyện tập

Which is the approximate percentage of oxygen, by volume, in clean, dry air?

(A) 1%
(C) 35%
(B) 21%
(D) 78%

Lời giải chi tiết

Clean, dry air is about 78% nitrogen, **21% oxygen**, and 1% other gases. **(B)**.

Bài tập luyện tập

Name the noble gas that makes up almost all of the "other gases" fraction (about 1%) of clean, dry air, and explain why water vapour is excluded from the standard composition figures.

Lời giải chi tiết

The gas is **argon**, Ar ($\approx 0.9\%$ by volume). Water vapour is excluded because its concentration in air is highly **variable** — from almost zero over a desert to several percent in humid tropical air — so the standard percentages are quoted for *dry* air, with water vapour and CO_2 treated as variable extras.

Bài tập luyện tập

Explain, in terms of its effect on the blood, why carbon monoxide is dangerous even at low atmospheric concentrations.

Lời giải chi tiết

Carbon monoxide binds to haemoglobin in red blood cells more strongly (and less reversibly) than oxygen does, forming carboxyhaemoglobin. This reduces the blood's capacity to carry oxygen to the body's tissues and organs, starving them of oxygen even when only a fraction of the haemoglobin is affected. Because CO is colourless and odourless, a dangerous build-up can occur without warning.

Bài tập luyện tập

Nitrogen oxides (NO_x) released from car exhausts mainly contribute to which environmental problem?

(A) Ozone layer depletion
(C) Eutrophication only
(B) Acid rain
(D) Global dimming only

Lời giải chi tiết

NO_x dissolves in atmospheric moisture and is oxidised to nitric acid, a major component of **acid rain**. **(B)**.

Bài tập luyện tập

A sample of 24 g of carbon undergoes *incomplete* combustion in a limited supply of oxygen: $2C + O_2 \rightarrow 2CO$. Calculate the mass of carbon monoxide produced.

Lời giải chi tiết

moles C $= \dfrac{24}{12} = 2$ mol. Mole ratio C : CO $= 2 : 2 = 1 : 1$, so moles CO $= 2$ mol.
mass CO $= 2 \times 28 = 56$ g.

Bài tập luyện tập

A car engine completely burns 228 g of octane, C_8H_{18} ($M_r = 114$): $2C_8H_{18} + 25O_2 -> 16CO_2 + 18H_2O$. Calculate the mass of CO_2 released.

Lời giải chi tiết

moles $C_8H_{18} = \dfrac{228}{114} = 2$ mol. Mole ratio C_8H_{18} : $CO_2 = 2 : 16 = 1 : 8$, so moles $CO_2 = 2 \times 8 = 16$ mol.
mass $CO_2 = 16 \times 44 = 704$ g.

Bài tập luyện tập

Write the balanced equation for the reaction between acid rain (sulfuric acid) and a limestone statue, and name two other named effects of acid rain besides damage to limestone.

Lời giải chi tiết

$CaCO_3 + H_2SO_4 -> CaSO_4 + H_2O + CO_2$. Other effects: **acidification of lakes and rivers**, killing fish and other aquatic life; and **damage to forests** (direct leaf damage plus leaching of soil nutrients and release of toxic aluminium ions that harm roots). (Corrosion of exposed metal structures is also acceptable.)

Bài tập luyện tập

Which pollutant is most directly associated with reduced visibility and "global dimming"?

(A) Carbon dioxide
(B) Particulates (soot)
(C) Nitrogen
(D) Argon

Lời giải chi tiết

Particulates (soot) scatter and reflect sunlight, reducing the solar radiation reaching the surface (global dimming), as well as causing respiratory harm. **(B)**.

Bài tập luyện tập

(Supplement) Explain why platinum and rhodium in a catalytic converter are described as catalysts rather than as reactants that are used up.

Lời giải chi tiết

Although CO and NO molecules adsorb onto the platinum/rhodium surface and react there, the metal atoms themselves are not chemically changed or consumed by the overall reaction — they are regenerated at the end of the surface reaction and remain available to speed up the reaction of further CO/NO molecules indefinitely. A true reactant would be permanently converted into new substances and used up as the reaction proceeds; the catalyst is not.

Bài tập luyện tập

(Supplement) Which equation correctly represents the reaction occurring inside a catalytic converter?

(A) $CO + NO -> CO_2 + N_2$
(C) $CO + 2NO -> CO_2 + N_2O$
(B) $2CO + 2NO -> 2CO_2 + N_2$
(D) $2CO + NO -> 2CO_2 + N$

Lời giải chi tiết

Only option (B), $2CO + 2NO -> 2CO_2 + N_2$, is balanced: C: $2 = 2$; O: $2 + 2 = 4$ on the left, $2 \times 2 = 4$ on the right; N: $2 = 2$. **(B)**.

Bài tập luyện tập

Which gas is considered the main contributor to the *enhanced* (human-caused) greenhouse effect?

(A) Nitrogen
(C) Carbon dioxide
(B) Argon
(D) Oxygen

Lời giải chi tiết

CO_2, released in vast quantities by burning fossil fuels, is the main greenhouse gas responsible for the enhanced greenhouse effect. **(C)**.

Bài tập luyện tập

Give two greenhouse gases (other than water vapour) responsible for the enhanced greenhouse effect, and state one human activity that increases the atmospheric concentration of each.

Lời giải chi tiết

Carbon dioxide, CO_2 — increased by burning fossil fuels (and by deforestation, which removes trees that would otherwise absorb CO_2).
Methane, CH_4 — increased by livestock farming (digestive gases from cattle) and by decomposition of waste in landfill sites.

Bài tập luyện tập

Explain the difference between the (natural) greenhouse effect and the enhanced greenhouse effect, and state why the distinction matters.

Lời giải chi tiết

The natural greenhouse effect is the normal process by which greenhouse gases trap enough infrared radiation to keep the Earth's surface warm enough to support life — it is essential and has existed for billions of years. The enhanced greenhouse effect refers specifically to the *additional* warming caused by human activities increasing greenhouse gas concentrations above their natural levels, driving global warming. The distinction matters because it clarifies that the goal is not to eliminate the greenhouse effect (which would make Earth uninhabitably cold) but to reduce the human-caused *increase* in it.

Bài tập luyện tập

State two distinct physical mechanisms by which global warming causes sea levels to rise.

Lời giải chi tiết

(1) **Thermal expansion**: as seawater warms, it expands slightly in volume, raising sea level even without any extra water being added. (2) **Melting land-based ice**: melting glaciers and polar ice sheets (on land, not sea ice) add extra liquid water to the oceans, directly increasing their volume.

Bài tập luyện tập

Which biological process removes carbon dioxide from the atmosphere?

(A) Respiration
(B) Combustion
(C) Photosynthesis
(D) Decay

Lời giải chi tiết

Photosynthesis, $6CO_2 + 6H_2O -> C_6H_{12}O_6 + 6O_2$, removes CO_2 from the air; the other three processes all *release* CO_2. **(C)**.

Bài tập luyện tập

Explain how fossil fuels form, and why burning them today has a much bigger short-term impact on atmospheric CO_2 than the natural carbon cycle alone.

Lời giải chi tiết

Fossil fuels form when the remains of dead plants and animals fail to fully decompose (e.g. buried in oxygen-poor sediment, swamps or seas) and are subjected to high pressure and temperature over millions of years, slowly converting them into coal, oil and natural gas. This process locks carbon away from the atmosphere for a very long time. Burning fossil fuels releases that carbon back into the atmosphere as CO_2 within decades, vastly faster than the millions of years it took to store it — so this carbon is added to the atmosphere far more quickly than natural sinks (photosynthesis, ocean absorption) can remove it, unbalancing the cycle and raising atmospheric CO_2.

Bài tập luyện tập

(Supplement) Explain how a warming ocean can reduce the ocean's ability to absorb atmospheric carbon dioxide, potentially accelerating atmospheric CO_2 increase.

Lời giải chi tiết

Gases are generally less soluble in warmer water than in cooler water. As ocean temperatures rise, the surface water can dissolve less CO_2 from the atmosphere, and some of the CO_2 already dissolved may be released back into the air (out-gassing). This reduces the effectiveness of the ocean as a carbon sink, meaning a larger share of human CO_2 emissions remains in the atmosphere, which can further accelerate warming — a self-reinforcing (positive feedback) effect.

Bài tập luyện tập

Explain why atmospheric nitrogen gas, N_2, cannot be used directly by most plants, and name two natural processes that convert it into a usable form.

Lời giải chi tiết

N_2 molecules are held together by an extremely strong triple covalent bond, making the gas very unreactive under ordinary conditions, so most plants cannot absorb or use N_2 directly. Two natural processes that "fix" it into usable compounds: **lightning** (its huge energy forces N_2 and O_2 to react, forming nitrogen oxides that reach the soil as nitrates in rain), and **nitrogen-fixing bacteria** (free-living in soil, or symbiotic in the root nodules of leguminous plants), which convert N_2 directly into usable nitrogen compounds.

Bài tập luyện tập

(Supplement) State the two stages of nitrification, naming the nitrogen species involved, and explain why nitrification is important for plant growth.

Lời giải chi tiết

Nitrifying bacteria first oxidise ammonium ions to nitrite ions ($NH_4^+ \rightarrow NO_2^-$), then oxidise nitrite ions to nitrate ions ($NO_2^- \rightarrow NO_3^-$). This matters because plants absorb nitrogen through their roots mainly as **nitrate ions**, so nitrification converts nitrogen released by decay (as ammonium) into the chemical form plants can actually take up and use to build proteins and other nitrogen-containing compounds.

Bài tập luyện tập

State one role of phosphorus as a plant nutrient in NPK fertiliser.

Lời giải chi tiết

Phosphorus (P) promotes healthy **root growth** and helps with seed and fruit formation (and is involved in the plant's energy-transfer compounds).

Bài tập luyện tập

(Supplement) Using $N_2 + 3H_2 \rightleftharpoons 2NH_3$, calculate the mass of ammonia that could be produced, in principle, from 56 kg of nitrogen gas, assuming complete conversion.

Lời giải chi tiết

moles $N_2 = \dfrac{56\,000}{28} = 2000$ mol. Mole ratio $N_2 : NH_3 = 1 : 2$, so moles $NH_3 = 4000$ mol.
mass $NH_3 = 4000 \times 17 = 68\,000$ g $= 68$ kg.

Bài tập luyện tập

A pond next to a farm receives runoff heavy in phosphate fertiliser. Over the following month, describe the chain of events that leads to large numbers of fish dying, referring explicitly to dissolved oxygen.

Lời giải chi tiết

The excess phosphate causes algae to grow explosively (an algal bloom), forming a dense surface layer that blocks light from reaching submerged plants, which then die from lack of photosynthesis. Bacteria decomposing this large mass of dead plant material respire aerobically, consuming dissolved oxygen faster than it can be replaced (e.g. by photosynthesis or diffusion from the air). The dissolved oxygen concentration falls too low to support fish and other aquatic animals, which suffocate and die in large numbers.

Bài tập luyện tập

Applying much more NPK fertiliser than a crop can absorb is most likely to lead directly to which environmental problem?

(A) Ozone depletion
(B) Acid rain
(C) Eutrophication
(D) Global dimming

Lời giải chi tiết

Excess nitrate and phosphate is washed into waterways by rain, over-enriching them with nutrients — this is **eutrophication**, ultimately causing oxygen depletion and fish kills. **(C)**.

Bài tập luyện tập

A student claims: "Because SO_2 and CO_2 are both released from burning fossil fuels, they must cause the same environmental problem." Explain why this statement is incorrect.

Lời giải chi tiết

SO_2 dissolves in atmospheric moisture and is oxidised to sulfuric acid, contributing mainly to **acid rain** — a local/regional acidity problem. CO_2 is a greenhouse gas that traps infrared radiation, contributing mainly to the **enhanced greenhouse effect and global warming** — a global temperature problem. Although both come from the same combustion sources, they act through entirely different chemical mechanisms and cause entirely different environmental effects.

Organic Chemistry

Mục tiêu Unit: Dãy đồng đẳng và danh pháp hydrocarbon; cấu trúc ankan/anken và đồng phân cấu tạo (Supplement); phản ứng cháy hoàn toàn/không hoàn toàn và phản ứng thế của ankan (Supplement); phản ứng cộng của anken (hydro hoá, hydrat hoá, cộng brom) và phép thử nước brom; chưng cất phân đoạn dầu mỏ và cracking; sản xuất rượu ethanol (lên men và hydrat hoá xúc tác) và quá trình oxi hoá thành axit ethanoic; tính chất axit carboxylic và phản ứng ester hoá (Supplement); polymer hoá cộng hợp và giới thiệu polymer trùng ngưng (Supplement) cùng vấn đề rác thải nhựa.

11.1 Homologous series

Organic chemistry is the study of compounds of carbon (excluding simple compounds such as CO_2, carbonates and oxides of carbon). Carbon atoms can form four strong covalent bonds and can link to each other in long chains, branched chains or rings, which is why so many different carbon compounds exist. A **homologous series** is a family of compounds that:

- have the same **general formula** (e.g. all alkanes fit C_nH_{2n+2});
- show a gradual **trend** in physical properties (melting point, boiling point, viscosity) as the number of carbon atoms increases;
- have similar **chemical properties**, because they contain the same functional group / type of bonding;
- differ from the next member of the series by one CH_2 unit (an increase of 14 in relative molecular mass).

Naming stems

Cambridge IGCSE Chemistry names organic compounds using a stem that tells you the number of carbon atoms in the longest chain, followed by an ending that tells you the homologous series:

C atoms	1	2	3	4	5	6	7	8	10 / 12
Stem	meth-	eth-	prop-	but-	pent-	hex-	hept-	oct-	dec- / dodec-

Endings: **-ane** (alkane), **-ene** (alkene), **-ol** (alcohol), **-oic acid** (carboxylic acid). For example *eth-* + *-ene* = ethene (C_2H_4); *but-* + *-ane* = butane (C_4H_{10}); *dec-* + *-ane* = decane ($C_{10}H_{22}$).

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Dãy đồng đẳng là một nhóm hợp chất có cùng công thức tổng quát, tính chất hoá học tương tự (do cùng loại liên kết/nhóm chức), và tính chất vật lý (nhiệt độ sôi, nhiệt độ nóng chảy, độ nhớt) biến đổi **đều đặn, có quy luật** khi mạch carbon dài thêm. Mỗi chất kế tiếp trong dãy hơn chất trước đúng một nhóm CH_2 (khối lượng phân tử tăng thêm 14). Tên gọi gồm phần **gốc** (meth-, eth-, prop-, but-,...chỉ số nguyên tử carbon) cộng phần **đuôi** chỉ dãy đồng đẳng (-ane: ankan, -ene: anken, -ol: rượu, -oic acid: axit carboxylic).

11.1.1 Alkanes and alkenes: the first members

The table below shows the structural formulas of the first four members of the alkane series and the first three members of the alkene series.

Name	Molecular formula	Structural formula
Methane	CH_4	CH_4
Ethane	C_2H_6	CH_3-CH_3
Propane	C_3H_8	$CH_3-CH_2-CH_3$
Butane	C_4H_{10}	$CH_3-CH_2-CH_2-CH_3$
Ethene	C_2H_4	$CH_2=CH_2$
Propene	C_3H_6	$CH_3-CH=CH_2$
But-1-ene	C_4H_8	$CH_3-CH_2-CH=CH_2$

First four members of the alkane homologous series (C_nH_{2n+2}, saturated, only C–C and C–H single bonds) and first three members of the alkene homologous series (C_nH_{2n}, unsaturated, one C=C double bond per molecule).

Quick reference — general formulas of the main organic homologous series:

Series	General formula	Functional group / bonding
Alkane	C_nH_{2n+2}	saturated, only C–C single bonds
Alkene	C_nH_{2n}	unsaturated, one C=C double bond
Alcohol	$C_nH_{2n+1}OH$	–OH (hydroxyl) group
Carboxylic acid	$C_nH_{2n+1}COOH$	–COOH (carboxyl) group

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Bảng trên liệt kê công thức cấu tạo của 4 ankan đầu tiên (methane, ethane, propane, butane — chỉ có liên kết đơn) và 3 anken đầu tiên (ethene, propene, but-1-ene — mỗi phân tử có một liên kết đôi C=C). Bảng "tra cứu nhanh" ghi công thức tổng quát của bốn dãy đồng đẳng thường gặp: ankan, anken, rượu (alcohol) và axit carboxylic — cần thuộc lòng để làm nhanh các bài cân bằng phương trình và xác định công thức phân tử.

11.1.2 Structural isomerism (Supplement)

(Supplement) **Structural isomers** are compounds with the *same molecular formula* but *different structural arrangements* of atoms — and therefore, often, different physical properties (e.g. different boiling points). The classic IGCSE example is butane, C_4H_{10}, which has two structural isomers:

Name	Structural formula	Boiling point
Butane (straight chain)	$CH_3-CH_2-CH_2-CH_3$	$-0.5\,^{\circ}C$
2-methylpropane (branched)	$CH_3-CH(CH_3)-CH_3$	$-11.7\,^{\circ}C$

Both have molecular formula C_4H_{10} — four carbon atoms and ten hydrogen atoms — but butane has a continuous four-carbon chain, while 2-methylpropane has a three-carbon main chain with a CH_3 branch on the middle carbon. Branching generally lowers the boiling point slightly, because branched molecules pack together less closely and have weaker intermolecular (van der Waals) forces between neighbouring molecules.

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Đồng phân cấu tạo (structural isomer) là các chất có **cùng công thức phân tử** nhưng **cấu**

trúc/cách sắp xếp nguyên tử khác nhau, dẫn đến tính chất vật lý khác nhau (ví dụ nhiệt độ sôi). Butane (C_4H_{10}) có 2 đồng phân: butane mạch thẳng và 2-methylpropane mạch nhánh. Do phân tử mạch nhánh "xếp khít" với nhau kém hơn mạch thẳng, lực van der Waals giữa các phân tử yếu hơn → nhiệt độ sôi thấp hơn.

11.2 Alkanes

Alkanes have general formula C_nH_{2n+2} and are **saturated** — every carbon–carbon bond is a single bond, and every carbon atom is bonded to as many hydrogen atoms as possible. Because C–C and C–H single (sigma) bonds are strong and non-polar, alkanes are **relatively unreactive**: they do not react with aqueous reagents such as bromine water, acids or alkalis. Their two key reactions at this level are **combustion** (burning in oxygen) and, for the Supplement, **substitution** with halogens.

11.2.1 Complete and incomplete combustion

When an alkane burns in a **plentiful supply of oxygen**, combustion is **complete**: every carbon atom is oxidised fully to carbon dioxide, and every hydrogen atom ends up in water.

$$C_3H_8 + 5O_2 -> 3CO_2 + 4H_2O \qquad (\text{propane, complete combustion}).$$

When the oxygen supply is **limited**, combustion is **incomplete**: some carbon is only partially oxidised to **carbon monoxide,** CO (a toxic, colourless, odourless gas), and/or some carbon is not oxidised at all and is released as fine **soot** (unburnt carbon particles).

$$2C_4H_{10} + 9O_2 \rightarrow 8CO + 10H_2O \qquad (\text{butane, incomplete combustion to CO}).$$

Complete combustion releases **more energy** per mole of fuel than incomplete combustion, because carbon is oxidised as far as possible (C^{+4} in CO_2, versus C^{+2} in CO). Incomplete combustion is dangerous in enclosed spaces (e.g. faulty gas boilers) because CO binds irreversibly to haemoglobin, preventing oxygen transport in the blood.

VN **GIẢI THÍCH TIẾNG VIỆT**

Khi ankan cháy trong **đủ oxi**, xảy ra **cháy hoàn toàn**: mọi carbon tạo thành CO_2, mọi hydro tạo thành H_2O. Khi **thiếu oxi**, xảy ra **cháy không hoàn toàn**: một phần carbon chỉ tạo **khí CO** (độc, không màu, không mùi) và/hoặc tạo **muội than** (carbon chưa cháy hết). Cháy hoàn toàn toả nhiều năng lượng hơn. Khí CO nguy hiểm vì bám chặt vào hemoglobin, ngăn máu vận chuyển oxi — đây là lý do tuyệt đối không đốt than/gas trong phòng kín thiếu thông gió.

11.2.2 Substitution reactions with halogens (Supplement)

(Supplement) Alkanes are unreactive towards bromine water in the dark, but in the presence of **ultraviolet (UV) light**, alkanes react slowly with chlorine or bromine in a **substitution reaction**: one hydrogen atom on the alkane is replaced by one halogen atom, and hydrogen halide gas is released as a by-product.

$$CH_4 + Cl_2 \xrightarrow{\text{UV light}} CH_3Cl + HCl$$

(methane → chloromethane + hydrogen chloride). If excess chlorine is present, further hydrogen atoms can be substituted in turn (e.g. CH_2Cl_2, $CHCl_3$, CCl_4), so substitution typically gives a mixture of products.

(!) Lỗi thường gặp: Do not confuse this with the addition reactions of alkenes (Section 11.3). Substitution: an alkane reacts with a halogen **only under UV light**, one atom is **swapped** for

another, and a **by-product** (HCl or HBr) is formed — the overall number of molecules stays the same. Addition: an alkene reacts with a halogen **even in the dark, at room temperature**, atoms are **added across the double bond**, and **no by-product** is formed — two molecules combine into one. If a question mentions "UV light" and an alkane, think substitution; if it mentions bromine water decolourising rapidly with no special conditions, think addition.

VN **GIẢI THÍCH TIẾNG VIỆT**
Ankan chỉ phản ứng với clo/brom khi có **ánh sáng UV**: một nguyên tử H bị **thay thế** bởi một nguyên tử halogen, sinh ra khí HCl/HBr — gọi là phản ứng **thế (substitution)**. Ngược lại, anken phản ứng **cộng (addition)** với brom ngay ở nhiệt độ phòng, không cần UV, và không sinh ra sản phẩm phụ — hai phân tử nhập thành một. Đây là lỗi rất hay gặp: nhầm lẫn giữa phản ứng cộng và phản ứng thế.

11.3 Alkenes

Alkenes have general formula C_nH_{2n} and are **unsaturated**: each molecule contains at least one carbon–carbon **double bond** (C = C). Because a double bond is a region of high electron density, alkenes are much **more reactive** than alkanes and undergo characteristic **addition reactions**, in which the double bond opens up and atoms from a second reactant add across the two carbon atoms — no other product is formed.

11.3.1 The bromine water test

Test for unsaturation (C=C double bond): shake the unknown hydrocarbon with orange/brown **bromine water**.

- **Alkene**: bromine water is rapidly **decolourised** (turns from orange/brown to colourless), even at room temperature and in the dark.
- **Alkane**: bromine water stays orange/brown — no reaction (in the absence of UV light).

The reason an alkene decolourises bromine water is that bromine **adds across the double bond**:

$$CH_2 = CH_2 + Br_2 -> CH_2Br - CH_2Br$$

Ethene reacts with bromine to form **1,2-dibromoethane**, a colourless liquid — so the orange bromine colour disappears as Br_2 is used up. The double bond opens: each carbon atom, previously double-bonded to the other, now forms a new single bond to one bromine atom.

(!) Lỗi thường gặp: The bromine water test only tells you whether a **C=C double bond** is present — it says nothing about any other feature of the molecule, and it cannot be used to prove a compound is a *pure* alkane just because it decolourises slowly (that slow fade, if it happens in bright light, is UV-catalysed substitution, not addition, and would also release steamy HBr/HCl fumes). To use bromine water as a clean, reliable distinguishing test between an alkane and an alkene, the test tube must be kept **out of direct sunlight/UV**, so that only the fast addition reaction of a genuine alkene is observed.

VN **GIẢI THÍCH TIẾNG VIỆT**
Phép thử nước brom: lắc mẫu với nước brom màu cam/nâu. **Anken** làm mất màu nhanh (brom cộng vào liên kết đôi C=C, ví dụ ethene + Br_2 → 1,2-dibromoethane, một chất lỏng không màu). **Ankan** không phản ứng, nước brom giữ nguyên màu (nếu không có ánh sáng UV). Lưu ý: phép thử này CHỈ xác nhận có liên kết đôi C=C, không chứng minh được điều gì khác — và

phải làm trong bóng tối để tránh nhầm với phản ứng thế chậm của ankan dưới ánh sáng UV.

11.3.2 Addition reactions of alkenes

Besides bromine, alkenes undergo addition with hydrogen and with steam (water).

Three key addition reactions of alkenes

1. **Hydrogenation** (addition of hydrogen): alkene + H_2 $\xrightarrow{\text{Ni catalyst, heat}}$ alkane.

$$CH_3CH=CH_2 + H_2 \xrightarrow{\text{Ni, } \sim 150\,^\circ\text{C}} CH_3CH_2CH_3$$

   This reaction is used industrially to convert liquid unsaturated vegetable oils (which contain many C=C double bonds) into solid saturated fats — the manufacture of **margarine**: hydrogen gas is bubbled through the heated oil in the presence of a nickel catalyst, saturating some of the double bonds and raising the melting point so the product is solid at room temperature.

2. **Hydration** (addition of steam): alkene + steam $\xrightarrow{\text{catalyst}}$ alcohol — this is the industrial route to ethanol and is developed fully in Section 11.6.

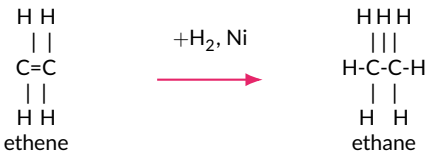
$$C_2H_4 + H_2O \xrightarrow{H_3PO_4,\ 300^\circ\text{C},\ 60\text{–}70\ \text{atm}} C_2H_5OH$$

3. **Halogenation** (addition of a halogen, e.g. bromine): as shown above, ethene + bromine → 1,2-dibromoethane.

In every case, the C=C double bond opens and one atom of the second reactant bonds to each of the two former double-bond carbons — a single addition product forms, with no by-product.

VN **GIẢI THÍCH TIẾNG VIỆT**

Ba phản ứng cộng quan trọng của anken: (1) **Cộng hydro (hydrogenation)**: anken + H_2 với xúc tác Ni, đun nóng → ankan — ứng dụng sản xuất margarine từ dầu thực vật không no. (2) **Cộng hơi nước (hydration)**: anken + hơi nước, xúc tác axit phosphoric → rượu — đây là cách sản xuất ethanol công nghiệp (xem mục 11.6). (3) **Cộng halogen**: anken + brom → hợp chất dibromo. Điểm chung: liên kết đôi C=C mở ra, mỗi nguyên tử carbon nhận thêm một liên kết đơn mới — không sinh sản phẩm phụ.

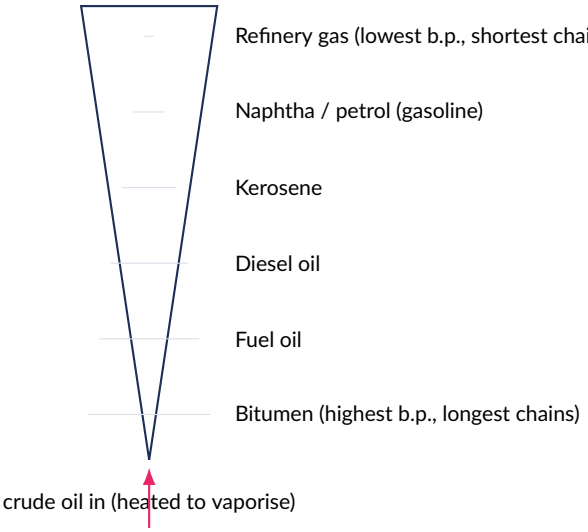


The C=C double bond in ethene opens during hydrogenation: one hydrogen atom bonds to each former double-bond carbon, giving the saturated alkane ethane.

11.4 Fractional distillation of crude oil

Crude oil is not a single compound but a **mixture of hydrocarbons** (mostly alkanes) of many different chain lengths. It has little direct use until it is separated into simpler, more useful fractions by **fractional distillation**, which exploits the fact that hydrocarbons with different chain lengths have different boiling points (longer chains → stronger van der Waals forces between molecules → higher boiling point).

Crude oil vapour is fed into the bottom of a tall fractionating column, which is hot at the bottom and progressively cooler towards the top. As vapour rises, each fraction condenses and is drawn off at the height where the column temperature falls below that fraction's boiling point; the shortest-chain molecules (which never condense inside the column) leave as gas at the very top.



Fractional distillation column: temperature falls from bottom to top. Short-chain hydrocarbons (low boiling point, volatile, low viscosity, highly flammable) rise highest before condensing; long-chain hydrocarbons (high boiling point, viscous, less flammable) condense low down or run off as a liquid residue at the bottom.

Fractions of crude oil, from top (lightest) to bottom (heaviest) of the column:

Fraction	Approx. chain length	Typical use
Refinery gas	C_1–C_4	bottled/piped gas for cooking and heating
Petrol / naphtha	C_5–C_{10}	fuel for cars (petrol); naphtha is feedstock for the petrochemical industry (making other chemicals, plastics)
Kerosene	C_{10}–C_{16}	aircraft (jet) fuel, domestic heating and lighting
Diesel oil	C_{15}–C_{25}	fuel for diesel road vehicles, trains
Fuel oil	C_{20}–C_{70}	fuel for ships and power stations
Bitumen	$> C_{70}$	surfacing roads, roofing felt

Trend down the column (top → bottom): chain length **increases**; boiling point **increases**; viscosity ("thickness") **increases**; volatility **decreases**; flammability (ease of ignition) **decreases**; colour typically darkens.

VN **GIẢI THÍCH TIẾNG VIỆT**

Dầu mỏ là hỗn hợp nhiều hydrocarbon (chủ yếu ankan) với độ dài mạch khác nhau, được tách bằng **chưng cất phân đoạn**: hơi dầu mỏ đi vào đáy tháp (nóng), càng lên cao tháp càng nguội — phân đoạn nào có nhiệt độ sôi thấp hơn nhiệt độ tại một độ cao nào đó sẽ ngưng tụ ở đó (mạch ngắn ngưng tụ ở cao, mạch dài ngưng tụ ở thấp hoặc chảy ra ở đáy). Càng xuống đáy tháp: mạch carbon càng dài, nhiệt độ sôi càng cao, độ nhớt càng lớn, độ bay hơi và khả năng bắt cháy càng giảm. Các phân đoạn chính (từ nhẹ đến nặng): khí đốt, xăng/naphtha, dầu hoả (kerosene), dầu diesel, dầu nhiên liệu (fuel oil), bitum.

11.5 Cracking

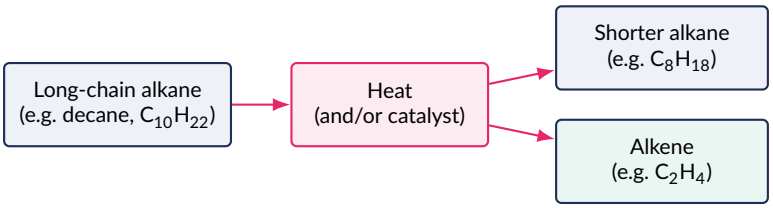
Fractional distillation alone does not match **supply** of crude oil fractions to market **demand**: crude oil naturally yields a large proportion of long-chain fractions (diesel, fuel oil, bitumen) but only a small proportion of short-chain fractions, while demand is the opposite — short-chain fuels (petrol, refinery gas) and small reactive alkenes (for making polymers) are in high demand. **Cracking** solves this mismatch by breaking long-chain alkane molecules into a mixture of shorter alkanes and alkenes.

Cracking

Cracking is the **thermal or catalytic decomposition** of large hydrocarbon molecules into smaller, more useful ones.

- **Thermal cracking**: long-chain alkane vapour is heated to a high temperature (typically $\sim 700^{\circ}\text{C}$ to 900°C) at high pressure, with no catalyst — this tends to favour a higher proportion of alkenes.
- **Catalytic cracking**: long-chain alkane vapour is passed over a hot catalyst (a zeolite / aluminium oxide catalyst) at a lower temperature and pressure than thermal cracking — cheaper to run, and gives mainly branched alkanes and aromatic hydrocarbons useful for petrol.

General pattern: **long-chain alkane** $\xrightarrow{\text{heat/catalyst}}$ **shorter-chain alkane** $+$ **one or more alkenes**. The total number of carbon atoms and the total number of hydrogen atoms must each balance between reactant and products (atoms are conserved).



Cracking schematic: a long-chain alkane is broken down, using heat and/or a catalyst, into a mixture of a shorter alkane and one or more alkenes. Carbon and hydrogen atom totals are conserved between reactant and products.

VN **GIẢI THÍCH TIẾNG VIỆT**

Chưng cất phân đoạn không giải quyết được vấn đề: dầu mỏ tự nhiên cho nhiều phân đoạn mạch dài (ít nhu cầu) nhưng ít phân đoạn mạch ngắn (nhu cầu cao — xăng, khí đốt, và anken để sản xuất polymer). **Cracking** là quá trình phân huỷ (bằng nhiệt và/hoặc xúc tác) các phân tử ankan mạch dài thành hỗn hợp ankan mạch ngắn hơn + anken. Cracking nhiệt (nhiệt độ rất cao, không xúc tác) cho nhiều anken hơn; cracking xúc tác (dùng xúc tác zeolite, nhiệt độ/áp suất thấp hơn) cho nhiều ankan mạch nhánh hơn, phù hợp làm xăng. Nguyên tắc cân bằng: tổng số nguyên tử C và H phải bảo toàn giữa chất đầu và sản phẩm.

11.6 Alcohols

11.6.1 Two routes to ethanol

Ethanol, C_2H_5OH, can be manufactured by two very different routes.

Route 1 — Fermentation

Yeast contains the enzyme **zymase**, which converts glucose into ethanol and carbon dioxide:

$$C_6H_{12}O_6 -> 2C_2H_5OH + 2CO_2$$

Conditions: warm temperature ($\approx$ 25°C to 30°C — warm enough for the enzyme to work quickly, but not so hot that it denatures); **anaerobic** (absence of oxygen — otherwise the ethanol would be oxidised further, or aerobic respiration would occur instead of fermentation); carried out as a **batch** process in a fermentation vessel, typically taking several days. Fermentation stops naturally once the ethanol concentration reaches about 15% (yeast is killed by higher concentrations), so the dilute mixture must then be **distilled** to concentrate the ethanol.

Route 2 — Catalytic hydration of ethene

Ethene reacts directly with steam over a catalyst:

$$C_2H_4 + H_2O -> C_2H_5OH$$

Conditions: steam, a **phosphoric(V) acid** (H_3PO_4) catalyst, a temperature of about 300 °C, and a pressure of about 60–70 atmospheres. Ethene itself is obtained from cracking crude oil fractions (Section 11.5), so this route depends on a **non-renewable** raw material. The reaction is run **continuously**, with unreacted ethene and steam recycled.

Comparing the two industrial routes to ethanol:

	Fermentation	**Catalytic hydration**
Raw material	glucose/sugar from plants (**renewable**)	ethene from cracking crude oil (**non-renewable**)
Rate of reaction	slow (days)	fast (essentially instantaneous over the catalyst)
Process type	**batch** (start, react, stop, empty, refill)	**continuous** (reactants fed in and product removed continuously)
Purity/yield	dilute (impure) ethanol solution — needs distillation to concentrate	concentrated, much purer ethanol produced directly
Energy demand	low (no need for high temperature/pressure)	high (requires $\sim$ 300 °C and 60–70 atm)

VN **GIẢI THÍCH TIẾNG VIỆT**

Ethanol có thể sản xuất bằng 2 cách: (1) **Lên men (fermentation)**: enzyme zymase trong men chuyển glucose thành ethanol + CO_2, điều kiện: ấm ($\approx$ 30°C), **kỵ khí** (không có oxi), là quá trình **gián đoạn (batch)**, nguyên liệu **tái tạo được** (đường thực vật), nhưng sản phẩm loãng cần chưng cất thêm. (2) **Hydrat hoá xúc tác**: ethene + hơi nước, xúc tác H_3PO_4, 300°C, 60–70 atm → ethanol tinh khiết trực tiếp; là quá trình **liên tục (continuous)**, nhanh hơn nhiều, nhưng nguyên liệu (ethene từ dầu mỏ) **không tái tạo được** và tốn nhiều năng lượng hơn.

11.6.2 Reactions of ethanol

Ethanol burns completely in a good supply of air/oxygen, releasing energy — this is why ethanol (and ethanol-blended petrol, "gasohol") is used as a fuel:

$$C_2H_5OH + 3O_2 -> 2CO_2 + 3H_2O$$

Ethanol can also be **oxidised** to ethanoic acid, CH_3COOH, in two common ways:

- **Microbial oxidation (souring)**: bacteria present in the air oxidise ethanol using atmospheric oxygen — this is how wine turns to vinegar if left open (a mixture of ethanoic acid and water) — which is why fermentation must be kept anaerobic while it is in progress.
- **Chemical oxidising agents**: warming ethanol with an oxidising agent such as acidified potassium dichromate(VI) (which itself is reduced, changing colour from orange to green) converts it to ethanoic acid:

$$C_2H_5OH + 2[O] -> CH_3COOH + H_2O$$

(the symbol [O] represents "oxygen from the oxidising agent").

VN **GIẢI THÍCH TIẾNG VIỆT**

Ethanol cháy hoàn toàn tạo CO_2 và H_2O (dùng làm nhiên liệu). Ethanol bị **oxi hoá** thành axit ethanoic (CH_3COOH) theo 2 cách: (1) do **vi khuẩn** trong không khí oxi hoá (rượu vang để hở không khí bị chua thành giấm) — đây là lý do quá trình lên men phải giữ kỵ khí; (2) dùng **tác nhân oxi hoá hoá học** như kali dichromate(VI) acid hoá (chuyển màu cam → xanh lục khi bị khử).

11.7 Carboxylic acids

Ethanoic acid, CH_3COOH, is the carboxylic acid found in vinegar. It is a **weak acid** — in aqueous solution it only partially ionises into H^+ and CH_3COO^- ions, so a solution of ethanoic acid has a higher pH (is less acidic) than a strong acid of the same concentration, such as hydrochloric acid. Despite being weak, ethanoic acid shows all of the typical reactions of an acid:

Typical reactions of ethanoic acid:

- **With reactive metals** → salt + hydrogen gas:

$$2CH_3COOH + Mg -> (CH_3COO)_2Mg + H_2$$

- **With carbonates** → salt + water + carbon dioxide gas:

$$2CH_3COOH + Na_2CO_3 -> 2CH_3COONa + H_2O + CO_2$$

- **With alkalis** (neutralisation) → salt + water:

$$CH_3COOH + NaOH -> CH_3COONa + H_2O$$

The salts of ethanoic acid are called **ethanoates** (e.g. magnesium ethanoate, sodium ethanoate).

VN **GIẢI THÍCH TIẾNG VIỆT**

Axit ethanoic (CH_3COOH, có trong giấm) là axit **yếu** (chỉ phân ly một phần trong nước) nhưng vẫn có đầy đủ tính chất hoá học của một axit: phản ứng với **kim loại** mạnh sinh khí H_2; phản ứng với **muối carbonate** sinh khí CO_2; phản ứng **trung hoà** với kiềm tạo muối + nước. Muối của axit ethanoic gọi là **ethanoate**.

11.7.1 Esterification (Supplement)

(Supplement) When a carboxylic acid reacts with an alcohol, in the presence of a strong acid catalyst (concentrated sulfuric acid) and gentle heating, an **ester** and water are formed:

$$CH_3COOH + C_2H_5OH \underset{\text{conc. } H_2SO_4,\ \text{heat}}{\rightleftharpoons} CH_3COOC_2H_5 + H_2O$$

Ethanoic acid + ethanol → **ethyl ethanoate** + water. This is a **condensation reaction**: two molecules join together with the loss of a small molecule (here, water).

Naming esters

An ester's name has two parts: **alkyl** (from the alcohol) + **alkanoate** (from the acid). For example:

- ethanoic acid + ethanol → **ethyl ethanoate** + water
- ethanoic acid + methanol → **methyl ethanoate** + water
- methanoic acid + ethanol → **ethyl methanoate** + water

Esters are typically volatile liquids with distinctive sweet or fruity smells, and are widely used as **flavourings** in food, in **perfumes**, and as **solvents** in industry (e.g. for paints, inks and lacquers).

VN **GIẢI THÍCH TIẾNG VIỆT**

Axit carboxylic phản ứng với rượu (xúc tác H_2SO_4 đặc, đun nóng) tạo **ester** + nước — đây là phản ứng **ngưng tụ** (mất đi một phân tử nhỏ, ở đây là nước). Ví dụ: axit ethanoic + ethanol → ethyl ethanoate + nước. Cách gọi tên ester: [gốc alkyl từ rượu] + [tên alkanoate từ axit]. Ester thường có mùi thơm ngọt/trái cây, dùng làm **hương liệu thực phẩm**, **nước hoa**, và **dung môi** công nghiệp.

11.8 Addition polymerisation

A **polymer** is a very long molecule built from many small, repeating units called **monomers**. In **addition polymerisation**, monomers containing a C = C double bond open up and join together, one after another, to form a long saturated chain. No other product is formed — *all* of the atoms in the monomer end up in the polymer (this is what makes it an "addition" polymerisation, as opposed to a condensation polymerisation).

$$n\ \mathrm{CH_2{=}CH_2} \xrightarrow{\text{heat, pressure, catalyst}} \left(\mathrm{{-}CH_2{-}CH_2{-}}\right)_n$$

Addition polymerisation of ethene: the C=C double bond in each monomer opens, allowing it to bond to its neighbours on both sides and link into a long chain — the repeat unit is enclosed in brackets with subscript n.

Repeat units of common addition polymers

- **Poly(ethene)** from ethene: $n\,\mathrm{CH_2{=}CH_2} \rightarrow (-\mathrm{CH_2-CH_2}-)_n$.
- **Poly(propene)** from propene: $n\,\mathrm{CH_3CH{=}CH_2} \rightarrow (-\mathrm{CH_2-CH(CH_3)}-)_n$.
- **Poly(chloroethene)** (PVC) from chloroethene: $n\,\mathrm{CH_2{=}CHCl} \rightarrow (-\mathrm{CH_2-CHCl}-)_n$.

In every case, notice: (i) the polymer name is "poly" + the monomer's name; (ii) the repeat unit contains exactly the same atoms as the monomer (just with the double bond replaced by two single bonds to neighbouring units); (iii) the subscript n (a very large number) shows that thousands of monomer units are joined in one polymer chain.

VN **GIẢI THÍCH TIẾNG VIỆT**

Polymer hoá cộng hợp: monomer chứa liên kết đôi C=C mở ra và nối tiếp nhau thành mạch dài; **không** sinh sản phẩm phụ nào khác (khác với polymer hoá ngưng tụ). Tên polymer = "poly" + tên monomer. Ví dụ: poly(ethene) từ ethene, poly(propene) từ propene, poly(chloroethene)/PVC

từ chloroethene. Đơn vị lặp lại (repeat unit) chứa đúng các nguyên tử của monomer, chỉ khác là liên kết đôi đã chuyển thành hai liên kết đơn nối với đơn vị bên cạnh.

11.8.1 Condensation polymers (Supplement)

(Supplement) In a **condensation polymerisation**, monomers with **two different reactive end groups** join together, and a **small molecule** (usually water) is lost at each new bond formed. A simplified example is the formation of a **polyester**, from a monomer with two –OH groups (a diol) reacting repeatedly with a monomer with two –COOH groups (a dicarboxylic acid):

$$n\,\mathrm{HO-X-OH} + n\,\mathrm{HOOC-Y-COOH} \rightarrow (\mathrm{-O-X-O-OC-Y-CO-})_n + 2n\,\mathrm{H_2O}$$

Unlike addition polymerisation, (i) **two different** monomers are usually needed (not one), and (ii) a small molecule (water) is **released as a by-product** at every new linkage, so the polymer contains slightly fewer atoms than the sum of the original monomers.

(!) **Lỗi thường gặp:** Do not describe condensation polymerisation as "the double bond opening" — polyester-forming monomers do not need a C=C double bond at all; instead, two *different* functional groups (here –OH and –COOH) react together and **eliminate a small molecule (water)** at each link. Addition polymers: one monomer, C=C required, no by-product. Condensation polymers: (typically) two different monomers, no C=C required, small molecule by-product (often water).

VN **GIẢI THÍCH TIẾNG VIỆT**

Polymer hoá ngưng tụ: thường cần **hai loại monomer khác nhau**, mỗi lần tạo liên kết mới sẽ giải phóng một **phân tử nhỏ** (thường là nước) — khác hẳn polymer hoá cộng hợp (chỉ 1 monomer có C=C, không sinh phụ phẩm). Ví dụ đơn giản hoá: monomer hai đầu –OH (diol) phản ứng với monomer hai đầu –COOH (diaxit) tạo **polyester**, giải phóng nước ở mỗi liên kết.

11.8.2 Plastic waste and disposal

Most addition polymers (e.g. poly(ethene), PVC) are **non-biodegradable**: microorganisms cannot break down their strong, unreactive carbon backbones, so they persist in the environment for decades or centuries. Three main disposal strategies are used:

- **Landfill**: cheap and simple, but non-biodegradable plastic takes up permanent space and landfill sites are filling up; buried plastic can leach additives into soil and groundwater.
- **Incineration (burning)**: reduces waste volume and can recover useful energy (heat/electricity), but incomplete combustion or burning of certain plastics (e.g. PVC, which contains chlorine) can release toxic gases such as HCl, and burning always releases CO_2, a greenhouse gas.
- **Recycling**: plastic waste is sorted by polymer type (often using resin identification codes), shredded, melted, and reformed into new products — this conserves crude oil (a non-renewable raw material) and reduces landfill and incineration, but requires the plastic to be correctly sorted and cleaned first.

Reducing the overall amount of single-use plastic produced, and reusing plastic items, are also important alongside recycling.

VN **GIẢI THÍCH TIẾNG VIỆT**

Hầu hết polymer cộng hợp **không phân huỷ sinh học** (vi sinh vật không phá vỡ được mạch carbon bền), tồn tại hàng chục/hàng trăm năm trong môi trường. Ba cách xử lý: **chôn lấp** (đơn giản nhưng chiếm diện tích vĩnh viễn, có thể rò rỉ chất phụ gia); **đốt** (giảm thể tích, thu năng lượng, nhưng có thể sinh khí độc như HCl khi đốt PVC, và luôn sinh CO_2); **tái chế** (phân loại theo loại nhựa, nghiền, nấu chảy, tạo sản phẩm mới — tiết kiệm dầu mỏ, giảm rác thải). Giảm sử dụng và tái sử dụng nhựa cũng quan trọng không kém tái chế.

11.9 Worked examples

Complete combustion of propane

Balance the equation for the complete combustion of propane, C_3H_8.

Carbon: 3 carbon atoms in C_3H_8 ⇒ 3 CO_2.
Hydrogen: 8 hydrogen atoms ⇒ 4 H_2O.
Oxygen: right-hand side needs $3 \times 2 + 4 \times 1 = 6 + 4 = 10$ oxygen atoms $= 5\,O_2$.

$$C_3H_8 + 5O_2 -> 3CO_2 + 4H_2O$$

Check: C: $3 = 3$; H: $8 = 8$; O: $10 = 6 + 4 = 10$. Balanced.

Incomplete combustion of butane

Butane, C_4H_{10}, burns in a limited supply of oxygen so that carbon monoxide (rather than carbon dioxide) is the only carbon-containing product. Balance the equation.

Start with 2 molecules of butane so that the hydrogen count (20) divides evenly: $2C_4H_{10}$ gives 8 carbon atoms ⇒ 8 CO, and 20 hydrogen atoms ⇒ 10 H_2O. Oxygen needed on the right: $8 \times 1 + 10 \times 1 = 18$ atoms $= 9\,O_2$.

$$2C_4H_{10} + 9O_2 \rightarrow 8CO + 10H_2O$$

Check: C: $8 = 8$; H: $20 = 20$; O: $18 = 8 + 10 = 18$. Balanced. (If oxygen is even more limited, some carbon may be released as soot, e.g. $2C_4H_{10} + 5O_2 \rightarrow 8C + 10H_2O$ — check O: $10 = 0 + 10 = 10$, balanced.)

Bromine water test — full explanation

Describe and explain what is observed when ethene gas is bubbled through orange bromine water.

Observation: the orange/brown colour of the bromine water rapidly disappears (decolourises).
Explanation: ethene is unsaturated (contains a C=C double bond). Bromine molecules add across the double bond:

$$CH_2 = CH_2 + Br_2 -> CH_2Br - CH_2Br$$

forming colourless 1,2-dibromoethane. As the orange Br_2 is used up (converted into a colourless product), the colour of the mixture fades. This reaction happens readily at room temperature with no special conditions needed, confirming it is an **addition** reaction, not a substitution.

Hydrogenation of propene

Propene, $CH_3CH = CH_2$, is reacted with hydrogen gas over a nickel catalyst. Write the equation and name the product.

Hydrogen adds across the C=C double bond, converting the unsaturated alkene into the corresponding saturated alkane:

$$CH_3CH = CH_2 + H_2 \xrightarrow{\text{Ni catalyst}} CH_3CH_2CH_3$$

Molecular check: $C_3H_6 + H_2 -> C_3H_8$; H: $6 + 2 = 8$. Product is **propane**.

Cracking — three worked problems

In each case, the total number of carbon atoms and the total number of hydrogen atoms must be the same on both sides of the equation.

1. **Decane cracked into octane and ethene:**

   $$C_{10}H_{22} -> C_8H_{18} + C_2H_4$$

   Check: C: $10 = 8 + 2$; H: $22 = 18 + 4 = 22$. Balanced.

2. **Dodecane is cracked to give octene, C_8H_{16}, and one other product.** Find the missing product.
   Let the missing product be C_xH_y: $C_{12}H_{26} -> C_xH_y + C_8H_{16}$. Carbon: $12 = x + 8 \Rightarrow x = 4$. Hydrogen: $26 = y + 16 \Rightarrow y = 10$. The missing product is C_4H_{10}; checking it fits the alkane formula C_nH_{2n+2}: $2(4) + 2 = 10$. **Missing product = butane, C_4H_{10}.**

3. **Octane is cracked to give hexane and one other product.** Find the missing product.
   $C_8H_{18} -> C_6H_{14} + C_xH_y$. Carbon: $8 = 6 + x \Rightarrow x = 2$. Hydrogen: $18 = 14 + y \Rightarrow y = 4$. The missing product is C_2H_4, which fits the alkene formula C_nH_{2n}: $2(2) = 4$. **Missing product = ethene, C_2H_4.**

Fermentation equation and conditions

Write the balanced equation for the fermentation of glucose and state the conditions required.

$$C_6H_{12}O_6 -> 2C_2H_5OH + 2CO_2$$

Check: C: $6 = 2(2) + 2(1) = 4 + 2 = 6$; H: $12 = 2(6) = 12$; O: $6 = 2(1) + 2(2) = 2 + 4 = 6$. Balanced.

Conditions: yeast (source of the enzyme zymase); warm temperature, $\approx 25°C$ to $30°C$ (fast enzyme action without denaturing it); **anaerobic** conditions (absence of oxygen, otherwise the ethanol would be oxidised, or the yeast would respire aerobically instead).

Esterification (Supplement)

(Supplement) Ethanoic acid reacts with ethanol in the presence of concentrated sulfuric acid. Write the equation, name the products, and state the type of reaction.

$$CH_3COOH + C_2H_5OH \xrightarrow{\text{conc. } H_2SO_4,\ \text{heat}} CH_3COOC_2H_5 + H_2O$$

Molecular check: left $C_2H_4O_2 + C_2H_6O = C_4H_{10}O_3$; right $C_4H_8O_2 + H_2O = C_4H_{10}O_3$. Balanced.
Products: ethyl ethanoate (a sweet-smelling ester) and water. **Reaction type**: condensation (a small molecule, water, is lost as the two reactants join).

Empirical and molecular formula of a hydrocarbon from combustion data

A sample of 0.58 g of a hydrocarbon is burned completely in excess oxygen, producing 1.76 g of CO_2 and 0.90 g of H_2O. Given that its relative molecular mass is 58, find its molecular formula.
Moles of $CO_2 = \dfrac{1.76}{44} = 0.04$ mol $\Rightarrow$ moles of C atoms $= 0.04$ mol $\Rightarrow$ mass of C $= 0.04 \times 12 = 0.48$ g.
Moles of $H_2O = \dfrac{0.90}{18} = 0.05$ mol $\Rightarrow$ moles of H atoms $= 0.05 \times 2 = 0.10$ mol $\Rightarrow$ mass of H $= 0.10 \times 1 = 0.10$ g.
Mass of C + mass of H $= 0.48 + 0.10 = 0.58$ g, which equals the original sample mass exactly — confirming the compound contains **only carbon and hydrogen** (no oxygen).
Mole ratio C : H $= 0.04 : 0.10 = 2 : 5 \Rightarrow$ **empirical formula** $= C_2H_5$ (empirical formula mass $= 2(12) + 5(1) = 29$).

$$\frac{M_r}{\text{empirical formula mass}} = \frac{58}{29} = 2 \;\Rightarrow\; \text{molecular formula} = (C_2H_5)_2 = C_4H_{10}\ (\text{butane}).$$

Structural isomers of butane (Supplement)

(Supplement) Draw and name the two structural isomers of C_4H_{10}.
Isomer 1 — butane (straight, unbranched chain of four carbons):

$$CH_3 - CH_2 - CH_2 - CH_3$$

Isomer 2 — 2-methylpropane (three-carbon main chain, with a CH_3 branch on the middle/second carbon):

$$CH_3 - CH(CH_3) - CH_3$$

Both have molecular formula C_4H_{10} (4 carbon atoms, 10 hydrogen atoms) — confirm by counting: butane has 4 carbons in a row, each end carbon bonded to 3 H and each middle carbon bonded to 2 H, giving $3 + 2 + 2 + 3 = 10$ H; 2-methylpropane has a central carbon bonded to 3 other carbons and 1 H, and three terminal CH_3 groups, giving $1 + 3(3) = 10$ H.

Repeat unit of poly(chloroethene) from its monomer

Chloroethene (vinyl chloride), $CH_2 = CHCl$, is polymerised to form PVC. Write the equation showing the repeat unit.
The C=C double bond opens; each monomer bonds to its neighbours on both sides, forming a long chain with exactly the same atoms as the monomer in each repeat unit:

$$n\,CH_2 = CHCl \rightarrow (-CH_2 - CHCl-)_n$$

The repeat unit, $-CH_2 - CHCl-$, is enclosed in brackets with subscript n to show that a very large number of monomer units are joined together.

11.10 Practice

Bài tập luyện tập

What is the general formula of the alkane homologous series?

(A) C_nH_{2n}
(B) C_nH_{2n+2}
(C) C_nH_{2n-2}
(D) C_nH_n

Lời giải chi tiết

Alkanes are saturated hydrocarbons with general formula C_nH_{2n+2}. **(B)**.

Bài tập luyện tập

Which simple chemical test distinguishes hex-1-ene from hexane?

(A) Add to water and check solubility
(B) Shake with bromine water in the dark
(C) Measure the melting point
(D) Burn in air and check the flame colour

Lời giải chi tiết

Hex-1-ene (an alkene) decolourises orange bromine water rapidly via addition across its C=C double bond; hexane (an alkane) does not react in the absence of UV light. **(B)**.

Bài tập luyện tập

State three features that define a homologous series.

Lời giải chi tiết

Any three of: same general formula; each member differs from the next by CH_2; similar chemical properties (same functional group/type of bonding); physical properties (e.g. boiling point) change gradually/show a trend as chain length increases.

Bài tập luyện tập

(Supplement) Draw the structural formulas of the two structural isomers of butane, C_4H_{10}, and name them.

Lời giải chi tiết

Butane (straight chain): $CH_3-CH_2-CH_2-CH_3$. 2-Methylpropane (branched): $CH_3-CH(CH_3)-CH_3$. Both have molecular formula C_4H_{10} but different arrangements of the carbon skeleton.

Bài tập luyện tập

(Supplement) Explain, in terms of intermolecular forces, why 2-methylpropane has a lower boiling point than butane even though both have the same molecular formula.

Lời giải chi tiết

Butane's straight-chain molecules can pack closely together and lie alongside each other over a larger surface area, giving stronger van der Waals forces between neighbouring molecules. 2-Methylpropane's branched, more compact shape reduces the contact area between molecules, weakening the van der Waals forces, so less energy is needed to separate the molecules — giving a lower boiling point.

Bài tập luyện tập

Write the balanced equation for the complete combustion of methane, CH_4.

Lời giải chi tiết

$CH_4 + 2O_2 -> CO_2 + 2H_2O$. Check: C: $1 = 1$; H: $4 = 4$; O: $4 = 2 + 2 = 4$. Balanced.

Bài tập luyện tập

Ethane burns in a limited supply of air, producing only carbon monoxide and water. Balance: $C_2H_6 + ?O_2 -> ?CO + ?H_2O$.

Lời giải chi tiết

2 carbon atoms $\Rightarrow$ 2 CO; 6 hydrogen atoms $\Rightarrow$ 3 H_2O; oxygen needed $= 2(1) + 3(1) = 5$ atoms $= 2.5\, O_2$. Multiplying through by 2 to clear the fraction: $2C_2H_6 + 5O_2 -> 4CO + 6H_2O$. Check: C: $4 = 4$; H: $12 = 12$; O: $10 = 4 + 6 = 10$. Balanced.

Bài tập luyện tập

Why is carbon monoxide dangerous even though it is colourless and odourless?

(A) It is explosive at room temperature

(B) It binds to haemoglobin in the blood, reducing oxygen transport

(C) It is strongly acidic

(D) It reacts violently with water

Lời giải chi tiết

Carbon monoxide binds to haemoglobin in red blood cells more strongly (and essentially irreversibly) than oxygen does, reducing the blood's ability to carry oxygen around the body — this is why it is toxic despite having no colour, smell or taste. **(B)**.

Bài tập luyện tập

(Supplement) Write the equation for the reaction of ethane with bromine in the presence of UV light, and name the type of reaction.

Lời giải chi tiết

$C_2H_6 + Br_2 \xrightarrow{\text{UV light}} C_2H_5Br + HBr$. This is a **substitution** reaction: one hydrogen atom on ethane is replaced by one bromine atom, with hydrogen bromide released as a by-product.

Bài tập luyện tập

(Supplement) A student claims that the reaction between methane and chlorine under UV light is an addition reaction because "two molecules react together". Explain why this claim is incorrect.

Lời giải chi tiết

Addition reactions require an unsaturated molecule (with a C=C double bond) that opens up so that the two reactants combine into a single product with no by-product. Methane is a saturated alkane with no double bond, so it cannot undergo addition. In the reaction with chlorine, one H atom on methane is replaced by one Cl atom, and HCl is released as a by-product ($CH_4 + Cl_2 -> CH_3Cl + HCl$) — this is **substitution**, not addition, even though two molecules are involved.

Bài tập luyện tập

Name the products when ethene reacts with bromine, and state the type of reaction.

Lời giải chi tiết

$CH_2 = CH_2 + Br_2 -> CH_2BrCH_2Br$ (1,2-dibromoethane). This is an **addition** reaction: the C=C double bond opens and one bromine atom bonds to each carbon, with no by-product formed.

Bài tập luyện tập

Which catalyst is used in the industrial hydrogenation of vegetable oils to make margarine?

(A) Platinum
(B) Nickel
(C) Phosphoric acid
(D) Manganese(IV) oxide

Lời giải chi tiết

Hydrogen gas is bubbled through the heated oil in the presence of a **nickel** catalyst, saturating some of the C=C double bonds and raising the melting point so the product is solid at room temperature. **(B)**.

Bài tập luyện tập

Write the equation for the catalytic hydration of ethene to ethanol, and state the catalyst and approximate conditions.

Lời giải chi tiết

$C_2H_4 + H_2O -> C_2H_5OH$. Catalyst: phosphoric(V) acid, H_3PO_4. Conditions: steam, $\approx 300\,^\circ$C, $\approx$60–70 atmospheres pressure.

Bài tập luyện tập

An alkene of molecular formula C_5H_{10} is shaken with bromine water. What would be observed, and why?

Lời giải chi tiết

The bromine water would rapidly decolourise (orange/brown → colourless), because C_5H_{10} fits the alkene general formula C_nH_{2n} ($n = 5$) and therefore contains a C=C double bond; bromine adds across this double bond to form a colourless dibromo-addition product.

Bài tập luyện tập

Which fraction of crude oil has the shortest average chain length and lowest boiling point?

(A) Bitumen
(B) Fuel oil
(C) Diesel oil
(D) Refinery gas

Lời giải chi tiết

Refinery gas consists of the shortest hydrocarbon chains (roughly C_1–C_4) and rises to the very top of the fractionating column, having the lowest boiling point of all the fractions. **(D)**.

Bài tập luyện tập

Explain, in terms of intermolecular forces, why longer-chain hydrocarbons have higher boiling points than shorter-chain hydrocarbons.

Lời giải chi tiết

Longer-chain molecules have a greater surface area of contact with neighbouring molecules, so the (van der Waals) intermolecular forces between them are stronger. More energy (a higher temperature) is therefore needed to separate the molecules and turn the liquid into a gas, so longer-chain hydrocarbons have higher boiling points.

Bài tập luyện tập

Name the crude oil fraction used as jet/aircraft fuel, and give its approximate chain length range.

Lời giải chi tiết

Kerosene, approximately C_{10}–C_{16}.

Bài tập luyện tập

Explain why long-chain hydrocarbon fractions from crude oil are cracked, rather than sold directly.

Lời giải chi tiết

Crude oil naturally yields a larger proportion of long-chain fractions than there is market demand for, while demand for short-chain fractions (e.g. petrol, refinery gas) and for small reactive alkenes (used to manufacture polymers) is much higher than the natural supply. Cracking breaks long-chain alkanes into shorter, more useful alkanes and alkenes, better matching supply to demand.

Bài tập luyện tập

Hexadecane, $C_{16}H_{34}$, is cracked to give octane, C_8H_{18}, and one other product. Find the molecular formula of the missing product and identify whether it is an alkane or alkene.

Lời giải chi tiết

Let the missing product be C_xH_y: $C_{16}H_{34} -> C_8H_{18} + C_xH_y$. Carbon: $16 = 8 + x \Rightarrow x = 8$. Hydrogen: $34 = 18 + y \Rightarrow y = 16$. Missing product $= C_8H_{16}$; since $2n = 2(8) = 16$, this fits the alkene general formula C_nH_{2n} — it is **octene**, an alkene.

Bài tập luyện tập

Propane, C_3H_8, is cracked into ethene and one other product. Find the missing product.

Lời giải chi tiết

$C_3H_8 -> C_2H_4 + C_xH_y$. Carbon: $3 = 2 + x \Rightarrow x = 1$. Hydrogen: $8 = 4 + y \Rightarrow y = 4$. Missing product $= CH_4$ (methane) — check it fits C_nH_{2n+2}: $2(1) + 2 = 4$. Balanced.

Bài tập luyện tập

State whether thermal cracking or catalytic cracking uses higher temperature and no catalyst.

Lời giải chi tiết

Thermal cracking uses very high temperature ($\sim$700–900°C) and high pressure with *no* catalyst, and tends to produce a higher proportion of alkenes. Catalytic cracking uses a lower temperature/pressure with a zeolite catalyst.

Bài tập luyện tập

Write the word and symbol equation for the fermentation of glucose, and state the conditions required.

Lời giải chi tiết

Glucose $\rightarrow$ ethanol + carbon dioxide: $C_6H_{12}O_6 -> 2C_2H_5OH + 2CO_2$. Conditions: yeast (contains the enzyme zymase), warm temperature ($\approx 30\,^\circ$C), and **anaerobic** (absence of oxygen) — oxygen would allow the ethanol to be oxidised further, or allow aerobic respiration instead of fermentation.

Bài tập luyện tập

Give one advantage and one disadvantage of producing ethanol by fermentation compared with catalytic hydration of ethene.

Lời giải chi tiết

Advantage: fermentation uses a renewable raw material (plant sugars) and needs no high temperature/pressure, so it is cheaper in energy terms. **Disadvantage**: fermentation is slow (a batch process taking days) and produces a dilute ethanol solution that must be distilled to

concentrate it, whereas catalytic hydration is fast, continuous, and gives concentrated ethanol directly (though it depends on non-renewable ethene from crude oil).

Bài tập luyện tập

What gas is produced when ethanoic acid reacts with sodium carbonate?

(A) Hydrogen
(B) Oxygen
(C) Carbon dioxide
(D) Sulfur dioxide

Lời giải chi tiết

Like all carboxylic/mineral acids, ethanoic acid reacts with carbonates to release CO_2: $2CH_3COOH + Na_2CO_3 -> 2CH_3COONa + H_2O + CO_2$. **(C)**.

Bài tập luyện tập

Write the equation for the reaction between ethanoic acid and magnesium, and name the salt formed.

Lời giải chi tiết

$2CH_3COOH + Mg -> (CH_3COO)_2Mg + H_2$. The salt formed is **magnesium ethanoate**.

Bài tập luyện tập

Explain why ethanoic acid is described as a "weak" acid, in terms of ionisation.

Lời giải chi tiết

A weak acid only **partially ionises** in aqueous solution — most of the ethanoic acid molecules remain un-ionised, with only a small fraction dissociating into H^+ and CH_3COO^- ions. This means a solution of ethanoic acid has a lower concentration of H^+ ions (a higher pH) than a strong acid of the same molar concentration, which fully ionises.

Bài tập luyện tập

(Supplement) Name the ester formed, and the type of reaction, when methanoic acid reacts with ethanol in the presence of concentrated sulfuric acid.

Lời giải chi tiết

$HCOOH + C_2H_5OH -> HCOOC_2H_5 + H_2O$. The ester is **ethyl methanoate**; the reaction is a **condensation** reaction (a small molecule, water, is lost as the acid and alcohol join together).

Bài tập luyện tập

(Supplement) State two everyday uses of esters.

Lời giải chi tiết

Any two of: food flavourings (fruity/sweet smells); perfumes and fragrances; solvents (e.g. for paints, inks, lacquers, nail-polish formulations).

Bài tập luyện tập

Which monomer is used to make poly(propene)?

(A) Ethene, $CH_2 = CH_2$

(B) Propene, $CH_3CH = CH_2$

(C) Propane, $CH_3CH_2CH_3$

(D) Propanol, C_3H_7OH

Lời giải chi tiết

The monomer's name matches the polymer's name, minus "poly": poly(propene) is made from **propene**. **(B)**.

Bài tập luyện tập

Write the equation showing the repeat unit formed when chloroethene, $CH_2 = CHCl$, undergoes addition polymerisation.

Lời giải chi tiết

$n\,CH_2 = CHCl \rightarrow (-CH_2 - CHCl-)_n$. The C=C double bond opens so each monomer bonds to its neighbours on both sides; the repeat unit contains exactly the atoms of the monomer.

Bài tập luyện tập

Explain why addition polymerisation produces no by-product, while the combustion reactions in this chapter always produce CO_2 and/or H_2O.

Lời giải chi tiết

In addition polymerisation, the C=C double bond in each monomer simply opens up so that new single bonds form directly between neighbouring monomer units — every atom originally present in the monomers is retained in the polymer chain, so nothing else is produced. Combustion, by contrast, is a chemical reaction with oxygen in which the C and H atoms of the fuel are entirely rearranged into new compounds (CO_2 and H_2O, or CO/soot if incomplete) — a fundamentally different (oxidation) reaction, not an addition reaction.

Bài tập luyện tập

(Supplement) Explain, using the idea of monomers and by-products, why forming a polyester is called a condensation reaction rather than an addition reaction.

Lời giải chi tiết

Condensation polymerisation typically joins two *different* monomers (e.g. a diol and a dicarboxylic acid) via their reactive end groups (–OH and –COOH), and at every new bond formed a small molecule — water — is released as a by-product, so the final polymer contains fewer atoms than the sum of all the original monomer atoms. Addition polymerisation uses one

monomer containing a C=C double bond, which simply opens to link monomers with no atoms lost; the polymer contains exactly the same atoms as all of the monomers combined.

Bài tập luyện tập

(Supplement) Give one advantage and one disadvantage of disposing of non-biodegradable plastic waste by incineration rather than landfill.

Lời giải chi tiết

Advantage: incineration greatly reduces the volume of waste and can recover useful energy (heat/electricity) from burning the plastic, unlike landfill where the space is simply lost permanently. **Disadvantage**: incineration releases CO_2 (a greenhouse gas) and, if the plastic contains chlorine (e.g. PVC) or combustion is incomplete, can release toxic gases such as HCl, CO or soot, requiring expensive gas-cleaning equipment to control.

Bài tập luyện tập

A hydrocarbon has empirical formula CH_2 and relative molecular mass 42. Find its molecular formula and state which homologous series it belongs to.

Lời giải chi tiết

Empirical formula mass of $CH_2 = 12 + 2(1) = 14$. $\dfrac{M_r}{\text{empirical mass}} = \dfrac{42}{14} = 3$, so molecular formula $= (CH_2)_3 = C_3H_6$. Since this fits the general formula C_nH_{2n} ($n = 3$), the compound is **propene**, a member of the **alkene** homologous series.

Bài tập luyện tập

Explain why bromine water decolourising slowly, only in bright sunlight and with steamy fumes given off, should *not* be interpreted as a positive test for an alkene.

Lời giải chi tiết

A genuine positive alkene test (addition) is fast, happens with no special light needed, and gives no fumes or gaseous by-product. Slow decolourisation that only occurs in bright light/UV, together with steamy fumes (hydrogen bromide gas), indicates that a **substitution** reaction is instead occurring between an alkane and bromine — this requires UV light to break the Br — Br bond and proceeds much more slowly, and releases HBr as a by-product, unlike true addition.

Bài tập luyện tập

Complete the word equation and state the missing condition: ethene + hydrogen $\xrightarrow{?}$ ethane.

Lời giải chi tiết

$C_2H_4 + H_2 \xrightarrow{\text{Ni catalyst}} C_2H_6$. The missing condition is a **nickel catalyst** (with heating); this is a hydrogenation (addition) reaction.

Ôn tập nhanh: Dãy đồng đẳng: cùng công thức tổng quát, hơn kém nhau CH_2, tính chất biến đổi đều. Ankan C_nH_{2n+2} (no, kém phản ứng, cháy hoàn toàn $\rightarrow CO_2 + H_2O$, cháy thiếu oxi $\rightarrow$ CO/muội than; phản ứng thế với halogen cần UV). Anken C_nH_{2n} (không no, có C=C, phản ứng cộng — brom, hydro/Ni, hơi nước/xúc tác axit; phép thử nước brom chỉ xác nhận C=C). Chưng cất phân đoạn tách dầu mỏ theo nhiệt độ sôi; cracking bẻ gãy mạch dài thành ankan ngắn + anken để cân bằng cung–cầu (bảo toàn số nguyên tử C, H khi cân bằng phương trình). Ethanol: lên men (tái tạo, gián đoạn, chậm, sản phẩm loãng) hoặc hydrat hoá xúc tác (không tái tạo, liên tục, nhanh, sản phẩm tinh khiết); ethanol bị oxi hoá thành axit ethanoic. Axit ethanoic là axit yếu, phản ứng đầy đủ với kim loại/carbonate/kiềm; phản ứng ester hoá (Supplement) với rượu tạo ester + nước (ngưng tụ). Polymer hoá cộng hợp: 1 monomer có C=C, không phụ phẩm; polymer hoá ngưng tụ (Supplement): thường 2 monomer khác nhau, mất phân tử nhỏ (nước); nhựa không phân huỷ sinh học cần xử lý bằng chôn lấp/đốt/tái chế.

Experimental Techniques and Chemical Analysis

Mục tiêu Unit: Phương pháp tách và tinh chế hỗn hợp (lọc, kết tinh, chưng cất đơn/phân đoạn, phễu chiết, sắc ký giấy); tiêu chí đánh giá độ tinh khiết; nhận biết khí, ion dương, ion âm bằng phép thử hoá học; xây dựng chiến lược phân tích định tính có hệ thống để xác định một muối chưa biết.

12.1 Separating and purifying mixtures

No natural sample is ever a single pure substance straight away — rocks, sea water, crude oil, and living tissue are all mixtures. This section builds up a toolkit of physical separation techniques, from the simplest (filtration) to more advanced ones (fractional distillation, chromatography), each suited to a particular type of mixture.

VN **GIẢI THÍCH TIẾNG VIỆT**

Không có mẫu vật nào trong tự nhiên là một chất tinh khiết duy nhất — đá, nước biển, dầu mỏ, mô sống đều là hỗn hợp. Phần này xây dựng một bộ công cụ tách vật lý, từ đơn giản nhất (lọc) đến nâng cao hơn (chưng cất phân đoạn, sắc ký), mỗi phương pháp phù hợp với một loại hỗn hợp nhất định.

12.1.1 Filtration and crystallisation

Khái niệm cốt lõi

Filtration separates an insoluble solid from a liquid (or from a solution). The mixture is poured through filter paper held in a funnel: the solid that is trapped on the paper is the **residue**; the liquid that passes through is the **filtrate**. The filter paper is usually folded into a cone (or fluted, with pleats, to speed up filtering) and rested inside a glass funnel supported over a beaker or conical flask by a retort stand and clamp, or simply resting in the neck of the receiving vessel. Fluting the paper (folding it into a fan of small pleats rather than a simple cone) increases the surface area of paper in contact with the liquid and creates air channels between the paper and the funnel wall, so the liquid drains through noticeably faster.

Crystallisation obtains a soluble solid from its solution as pure, well-formed crystals. Procedure: (1) heat the solution gently to evaporate off *some* of the solvent until the solution is **saturated** — tested by dipping a cold glass rod into the solution and checking whether crystals form on it, or by watching for a thin crust starting to form on the surface; (2) stop heating and allow the hot saturated solution to **cool slowly and undisturbed**, so that crystals grow; (3) filter to collect the crystals; (4) wash them with a little cold solvent (to remove surface impurities without dissolving much of the product); (5) dry between filter paper or in a warm oven below the product's decomposition temperature.

VN **GIẢI THÍCH TIẾNG VIỆT**

Lọc (filtration) tách chất rắn không tan ra khỏi chất lỏng: phần rắn giữ lại trên giấy lọc gọi là **residue** (bã lọc), phần lỏng chảy qua gọi là **filtrate** (dịch lọc).
Kết tinh (crystallisation) thu được chất rắn tan dưới dạng tinh thể tinh khiết: đun nóng nhẹ để bay hơi *một phần* dung môi đến khi dung dịch **bão hoà**, sau đó để nguội **từ từ, không khuấy** cho tinh thể lớn dần, rồi lọc, rửa bằng một ít dung môi lạnh và làm khô.

Crucially, heating must **stop once the solution is saturated** — never boil the solution completely to dryness. If all the solvent is driven off, any dissolved impurities that were present in small amounts get trapped inside (or coat) the solid residue instead of staying behind in solution; strong continued heating can also decompose or char a heat-sensitive product. Cooling a hot *saturated* solution instead works because the solubility of most solids decreases as temperature falls, so the desired compound crystallises out selectively while the (smaller amount of) impurities mostly remain dissolved in the small volume of liquid left behind (the "mother liquor"), which is removed by filtration.

VN **GIẢI THÍCH TIẾNG VIỆT**

Phải **dừng đun** ngay khi dung dịch bão hoà, **không** đun cạn hoàn toàn — nếu cô cạn hết dung môi, tạp chất hoà tan sẽ bị giữ lại lẫn trong tinh thể. Làm nguội từ từ dung dịch bão hoà giúp chất cần kết tinh tách ra trước (vì độ tan giảm khi nhiệt độ giảm), còn tạp chất (lượng ít) vẫn ở lại trong phần dung dịch còn sót ("dung dịch mẹ"), sau đó bị loại bỏ khi lọc.

Ví dụ mẫu · Worked example — separating sand, salt and water

Describe how a mixture of sand, common salt and water could be separated so that dry salt crystals are recovered.

Step 1 — Filtration: pour the mixture through filter paper. Sand is insoluble, so it stays behind as the *residue*; the salt solution passes through as the *filtrate*.
Step 2 — Evaporation to saturation: gently heat the filtrate to evaporate some of the water until the solution is saturated (tested with a cold glass rod).
Step 3 — Crystallisation: stop heating and allow the hot saturated solution to cool slowly, so that salt crystals form.
Step 4 — Filter, wash, dry: filter off the crystals, rinse with a little cold water, and dry them between filter paper.
(If a sample of the pure water itself were also needed, the filtrate could instead be **simply distilled**: the water distils off and is collected as the distillate, while the salt becomes more concentrated and eventually crystallises in the flask — boiling the filtrate fully to dryness by evaporation alone would waste the water as escaped vapour instead of collecting it.)

12.1.2 Recrystallisation to increase purity

Khái niệm cốt lõi

If the crystals obtained are still not pure enough (e.g. the melting point range is too wide), **recrystallisation** can improve purity further: (1) dissolve the impure solid in the *minimum* volume of hot solvent needed to just dissolve it; (2) filter the hot solution quickly (using a heated funnel, to avoid crystals forming in the funnel) to remove any insoluble impurities; (3) allow the filtrate to cool slowly, so that crystals of the desired compound grow, while soluble impurities (present in only small amounts) remain dissolved in the mother liquor; (4) filter, wash with a little cold solvent, and dry. Repeating this cycle removes progressively more impurity, at the cost of some loss of product each time.

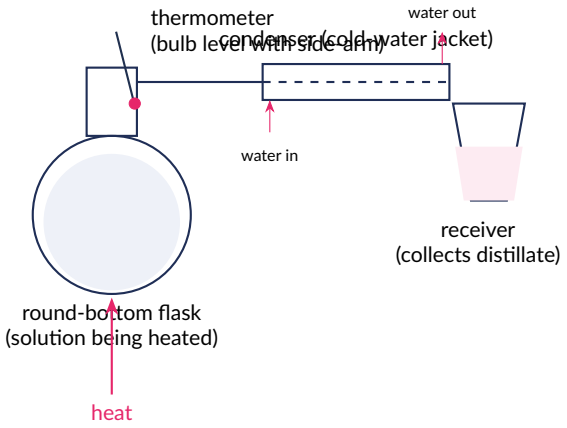
VN **GIẢI THÍCH TIẾNG VIỆT**

Kết tinh lại (recrystallisation) giúp tăng độ tinh khiết khi tinh thể thu được lần đầu chưa đủ sạch: hoà tan chất rắn trong **lượng tối thiểu** dung môi nóng, lọc nóng nhanh để loại tạp chất không tan, để nguội từ từ cho tinh thể lớn lên (tạp chất tan ở lại trong dung dịch mẹ), rồi lọc, rửa, làm khô. Có thể lặp lại nhiều lần để tăng độ tinh khiết, nhưng mỗi lần sẽ hao hụt một phần sản phẩm.

12.1.3 Simple distillation

Khái niệm cốt lõi

Simple distillation separates a solvent from a solution (e.g. pure water from salt water), or separates two liquids with very different boiling points. The solution is boiled; the vapour of the more volatile component rises and is cooled back into a liquid, which is collected separately from the substance left behind in the flask.



Simple distillation apparatus. The **flask** holds and heats the solution; the **thermometer** bulb sits level with the side-arm to record the temperature of the vapour leaving (not the liquid below); the **condenser** uses counter-current cold water (in at the bottom, out at the top) to cool vapour back into liquid; the **receiver** collects the pure distillate.

VN **GIẢI THÍCH TIẾNG VIỆT**

Chưng cất đơn (simple distillation) tách dung môi ra khỏi dung dịch bằng cách đun sôi và ngưng tụ hơi. Bầu nhiệt kế đặt ngang mức nhánh bên để đo đúng nhiệt độ của **hơi** đang bay ra (không phải nhiệt độ chất lỏng trong bình); ống sinh hàn (condenser) làm nước lạnh chảy ngược chiều với hơi để ngưng tụ hiệu quả; bình hứng thu lấy dịch chưng cất tinh khiết.

Khái niệm cốt lõi

A few **anti-bumping granules** (small pieces of unglazed, porous material) are often added to the flask before heating. They provide tiny pockets of trapped air that release a steady stream of small bubbles as the liquid is heated, promoting smooth, even boiling and preventing violent, unpredictable "bumping" (sudden large bubbles that can throw hot liquid up the flask or out of the apparatus). Anti-bumping granules should never be added to an already-hot liquid, as this can itself cause dangerous, sudden bumping.

VN **GIẢI THÍCH TIẾNG VIỆT**

Đá bọt chống trào (anti-bumping granules) là các mảnh vật liệu xốp cho vào bình trước khi

đun, tạo dòng bọt khí nhỏ đều giúp chất lỏng sôi êm, tránh hiện tượng "trào sôi đột ngột" (bumping) có thể bắn chất lỏng nóng ra ngoài. Tuyệt đối không thêm đá bọt vào chất lỏng đã nóng, vì có thể gây trào đột ngột ngay lập tức.

12.1.4 Fractional distillation

Khái niệm cốt lõi

Fractional distillation separates two or more *miscible* liquids with different (often close) boiling points using a **fractionating column** packed with glass beads or rings, which greatly increases the surface area available for repeated evaporation–condensation. As vapour rises up the column, it partially condenses and re-evaporates many times; at each stage the vapour becomes richer in the more volatile (lower boiling point) component. This allows the more volatile liquid to be collected first, near-pure, at the top of the column.

VN **GIẢI THÍCH TIẾNG VIỆT**

Chưng cất phân đoạn (fractional distillation) tách các chất lỏng **tan lẫn hoàn toàn** nhưng có nhiệt độ sôi khác nhau, nhờ cột phân đoạn nhồi bi thuỷ tinh làm tăng diện tích bề mặt cho hơi ngưng tụ — bay hơi lặp đi lặp lại nhiều lần, giúp thành phần dễ bay hơi hơn (nhiệt độ sôi thấp hơn) tách ra trước, gần như tinh khiết, ở đỉnh cột.

Ví dụ mẫu · Worked example — ethanol and water

Ethanol (boiling point $78\,^{\circ}$C) and water (boiling point $100\,^{\circ}$C) are miscible. Explain how fractional distillation separates them.

On heating the mixture, both liquids evaporate, but the vapour is richer in ethanol because it is more volatile. As this vapour rises through the fractionating column, it repeatedly cools, condenses, and re-evaporates on the packing; each cycle enriches the vapour further in ethanol (the lower-boiling component) while liquid richer in water trickles back down. Once the temperature at the top of the column reaches and holds steady around $78\,^{\circ}$C, near-pure ethanol vapour is passing over; this is condensed in a condenser and collected. The temperature must rise toward $100\,^{\circ}$C before the water fraction distils over.

This is the same principle used to separate the fractions of **crude oil** in a refinery fractionating column (see the Fuels section of the Organic Chemistry unit): the column is hot at the bottom and progressively cooler towards the top, so short-chain hydrocarbons with low boiling points (e.g. refinery gas, gasoline) rise furthest and are collected near the top, while long-chain hydrocarbons with high boiling points (e.g. bitumen) condense low down and are drawn off near the bottom.

12.1.5 Separating funnel for immiscible liquids (Supplement)

Khái niệm cốt lõi (Supplement)

A **separating funnel** separates two **immiscible** liquids (liquids that do not mix, e.g. oil and water). The mixture is poured in and left to settle into two distinct layers, with the denser liquid at the bottom. The tap is opened carefully to run the lower layer out into a container; the tap is closed *before* the upper layer reaches it, leaving the upper layer behind in the funnel to be poured out separately.

VN **GIẢI THÍCH TIẾNG VIỆT**

Phễu chiết (separating funnel) tách hai chất lỏng **không tan lẫn** (ví dụ dầu và nước): hỗn hợp tách thành hai lớp theo tỉ trọng, mở khoá cho lớp dưới (đậm đặc hơn) chảy ra trước, đóng khoá kịp thời trước khi lớp trên chảy tới, rồi lấy lớp trên riêng ra khỏi phễu.

Ví dụ mẫu · Worked example (Supplement)

A separating funnel contains a mixture of an organic solvent (density $0.87\,\text{g/cm}^3$) and water (density $1.00\,\text{g/cm}^3$). Which liquid forms the upper layer, and which layer should be run off first?

The organic solvent is **less dense** than water, so it floats on top, forming the **upper** layer, while water forms the denser **lower** layer. The lower layer (water) should be run off **first** through the tap, which is then closed as soon as the organic solvent reaches it; the organic layer is then poured out separately from the top of the funnel.

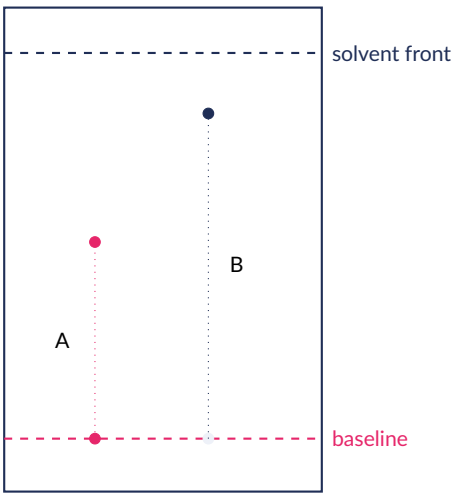
12.1.6 Paper chromatography

Khái niệm cốt lõi

Paper chromatography separates dissolved substances in a mixture according to how strongly each is attracted to the paper (the **stationary phase**) compared with the solvent (the **mobile phase**). A small spot of the mixture is placed above the level of the solvent in the container; as the solvent soaks up the paper, components that are more strongly attracted to the solvent (and less to the paper) travel further, separating the mixture into distinct spots.

$$R_f = \frac{\text{distance moved by spot (from baseline)}}{\text{distance moved by solvent front (from baseline)}}$$

R_f is always between 0 and 1, has no units, and is characteristic of a given substance in a given solvent at a given temperature — so it can be used to identify substances by comparison with known reference values run under identical conditions. The starting spot (the **origin**) must be marked *above* the level of the solvent in the container: if the spot itself were submerged in the solvent, the sample would simply dissolve straight into the solvent bulk and wash away, rather than being carried steadily up the paper as the solvent rises past it.



origin (spot loaded here)

Chromatogram with two components: A has moved 2.6 cm and B has moved 4.3 cm from the baseline, while the solvent front has moved 5.1 cm. So $R_f(\text{A}) = 2.6/5.1 \approx 0.51$ and $R_f(\text{B}) = 4.3/5.1 \approx 0.84$.

VN GIẢI THÍCH TIẾNG VIỆT

Sắc ký giấy tách các chất tan dựa trên mức độ chúng bị hút bởi giấy (pha tĩnh) so với dung môi (pha động). $R_f = \dfrac{\text{quãng đường vết chất di chuyển}}{\text{quãng đường dung môi di chuyển}}$, luôn nằm trong khoảng 0 đến 1, không có đơn vị, và là hằng số đặc trưng cho một chất trong một dung môi ở một nhiệt độ nhất định — nên dùng để nhận diện chất bằng cách so với giá trị tham chiếu đã biết, đo trong cùng điều kiện.

As soon as the chromatogram is removed from the solvent tank, the position of the **solvent front** should be marked immediately (usually by pencil, which does not dissolve in the solvent) — if left too long, the solvent continues to spread and evaporate unevenly across the paper, making the distance measurement unreliable. A given substance may also appear to give only one spot in one solvent, yet separate into two or more spots in a different solvent; testing an unknown mixture in more than one solvent therefore gives more reliable evidence about how many different substances it actually contains.

VN GIẢI THÍCH TIẾNG VIỆT

Ngay khi lấy giấy sắc ký ra khỏi bể dung môi, cần đánh dấu ngay vị trí **mực dung môi** (thường bằng bút chì, không tan trong dung môi) — để lâu, dung môi tiếp tục lan và bay hơi không đều khiến phép đo sai lệch. Một chất có thể chỉ cho một vết trong dung môi này nhưng tách thành nhiều vết trong dung môi khác, nên thử với nhiều loại dung môi giúp xác định số lượng chất trong hỗn hợp đáng tin cậy hơn.

Ví dụ mẫu · Worked example

On a chromatogram, a dye spot travels 6.4 cm from the baseline while the solvent front travels 8.0 cm. Calculate its R_f value.

$$R_f = \frac{6.4}{8.0} = 0.80.$$

Ví dụ mẫu · Worked example (variant)

On the same chromatogram, a second, different dye spot travels 3.4 cm from the baseline while the solvent front travels 8.5 cm. Calculate its R_f value, and state one condition that must be kept the same for a comparison with a reference value to be valid.

$$R_f = \frac{3.4}{8.5} = 0.40.$$

The comparison is only valid if the reference substance is run **on the same paper, in the same solvent, at the same temperature** (ideally on the same chromatogram, side by side).

Khái niệm cốt lõi (Supplement)

Some substances (e.g. many amino acids) are colourless and cannot be seen directly on a chromatogram. A **locating agent** — a chemical spray that reacts with the spots to produce colour (e.g. ninhydrin turns amino acid spots purple) — or viewing the paper under **ultraviolet light** (spots may fluoresce, or show as dark patches on a fluorescent background) is used to reveal

their positions so that R_f values can be measured.

VN **GIẢI THÍCH TIẾNG VIỆT**

Với chất **không màu** (ví dụ nhiều amino acid), cần dùng **thuốc thử hiện màu** (locating agent) — ví dụ phun ninhydrin để vết hiện màu tím — hoặc chiếu **đèn tử ngoại (UV)** để thấy vị trí vết trước khi đo R_f.

12.1.7 Choosing a separation method

With several techniques now available, the key skill is matching the *type of mixture* to the correct method.

Type of mixture	Suitable method
Insoluble solid + liquid	Filtration
Soluble solid dissolved in a liquid (recover the solid)	Crystallisation (or evaporation to dryness for a heat-stable solid)
Solvent to be recovered from a solution	Simple distillation
Two or more miscible liquids with different boiling points	Fractional distillation
Two immiscible liquids	Separating funnel
Dissolved substances with different attractions to paper/solvent	Paper chromatography
Solid mixture where one component is magnetic	Magnetic separation (no filtration/heating needed)

A quick reference for selecting a separation technique based on the nature of the mixture.

VN **GIẢI THÍCH TIẾNG VIỆT**

Bảng tổng hợp giúp chọn **đúng phương pháp** theo loại hỗn hợp: rắn không tan + lỏng → lọc; rắn tan (muốn thu lại rắn) → kết tinh; thu lại dung môi → chưng cất đơn; nhiều chất lỏng tan lẫn, nhiệt độ sôi khác nhau → chưng cất phân đoạn; hai chất lỏng không tan lẫn → phễu chiết; các chất tan có ái lực khác nhau với giấy/dung môi → sắc ký giấy.

Ví dụ mẫu · Worked example — safe heating of a flammable liquid

Explain why a Bunsen burner with a naked flame should *not* be used to heat ethanol directly during a distillation, and suggest a safer alternative.

Ethanol vapour is highly flammable; heating an open flask of ethanol directly over a naked flame risks the vapour catching fire or the liquid igniting, especially if it splutters or overflows. A safer alternative is to heat the flask indirectly, using an **electric heating mantle** or a **water bath** (for liquids that boil below $100\,^{\circ}$C), which avoids any naked flame near the flammable vapour.

12.2 Criteria of purity

Khái niệm cốt lõi

A chemically **pure** substance has one sharp, fixed melting point and one sharp, fixed boiling point, both matching known reference values. An **impure** substance (i.e. a mixture, even if only slightly contaminated) melts over a *range* of temperatures — usually starting *below* the true melting point of the pure substance — and boils over a range *above* the pure boiling point.

Reasoning: particles of an impurity disrupt the regular arrangement of particles in the solid lattice, weakening the forces holding it together in places, so less energy (a lower temperature) is needed to begin melting; because the impurity is not evenly distributed at a fixed concentration throughout, melting is not complete at one single temperature but spreads over a range as different regions finish melting at slightly different temperatures.

VN **GIẢI THÍCH TIẾNG VIỆT**

Chất **tinh khiết** có nhiệt độ nóng chảy và nhiệt độ sôi **cố định, sắc nét**. Chất **không tinh khiết** (hỗn hợp) nóng chảy trong một **khoảng nhiệt độ**, thường bắt đầu **thấp hơn** điểm nóng chảy thật, vì tạp chất làm gián đoạn mạng tinh thể (giảm điểm bắt đầu chảy) và phân bố không đều (khiến quá trình chảy trải dài thành một khoảng thay vì một điểm).

12.2.1 Determining melting points practically

Khái niệm cốt lõi

A small amount of the dry solid is packed into the closed end of a thin, sealed capillary tube, which is attached to a thermometer with a rubber band or wire. The thermometer and tube are lowered into an oil bath (or a Thiele tube of oil), which is heated **slowly and evenly**. The temperature is recorded at which the solid **first starts to melt** and the temperature at which it has **completely melted**; this range (or single value, for a pure substance) is the measured melting point.

VN **GIẢI THÍCH TIẾNG VIỆT**

Xác định điểm nóng chảy thực nghiệm: nhồi một ít mẫu rắn khô vào đầu kín của ống mao dẫn, gắn vào nhiệt kế, nhúng vào bể dầu (hoặc ống Thiele) và đun **chậm, đều**. Ghi lại nhiệt độ mẫu **bắt đầu chảy** và nhiệt độ **chảy hoàn toàn** — khoảng cách giữa hai giá trị này (hoặc một giá trị duy nhất với chất tinh khiết) chính là điểm nóng chảy đo được.

Khái niệm cốt lõi

Determining boiling points practically: a sample of the liquid is heated gently in a flask fitted with a thermometer (bulb in the vapour, as in simple distillation), and the temperature is recorded once it becomes **steady** while the liquid boils steadily. A **pure** liquid boils at one constant, sharp temperature throughout boiling; an **impure** liquid (e.g. a solution) boils over a rising range, since as the more volatile component is used up the composition of what remains changes and its boiling point drifts.

VN **GIẢI THÍCH TIẾNG VIỆT**

Xác định điểm sôi thực nghiệm: đun nhẹ chất lỏng trong bình có gắn nhiệt kế (bầu nằm trong phần hơi), ghi nhiệt độ khi nó **ổn định** trong lúc sôi đều. Chất lỏng **tinh khiết** sôi ở một nhiệt độ **cố định** suốt quá trình; chất lỏng **không tinh khiết** sôi ở nhiệt độ tăng dần theo thời gian vì thành phần còn lại thay đổi khi phần dễ bay hơi mất dần.

Ví dụ mẫu · Worked example

A solid is known to be pure sample X with a melting point of exactly $118\,^{\circ}$C. An unknown sample thought to be X is tested and is found to melt gradually between $110\,^{\circ}$C and $116\,^{\circ}$C. What does this show?

The unknown sample is **not pure X**: it melts *below* the true melting point of pure X and over a *range* ($6\,^{\circ}$C wide) rather than sharply at $118\,^{\circ}$C. This is consistent with the sample containing some impurity mixed with X (or being a different substance entirely — a genuine sample of pure X would melt sharply at $118\,^{\circ}$C).

In chromatography, a **pure** substance gives a **single spot** (in any solvent); a **mixture** gives **multiple spots** (or a streaky smear). An unknown substance can be identified by running it alongside **reference substances** on the same chromatogram, under identical conditions, and comparing R_f values (or matching spot positions directly).

VN **GIẢI THÍCH TIẾNG VIỆT**

Sắc ký: chất **tinh khiết** cho **một vết duy nhất**; **hỗn hợp** cho **nhiều vết**. Muốn nhận diện chất chưa biết, chạy song song với các **chất tham chiếu** đã biết trên cùng một tờ giấy, cùng dung môi, rồi so sánh giá trị R_f hoặc vị trí vết.

Ví dụ mẫu · Worked example — identifying an unknown dye

An unknown dye is run on a chromatogram alongside three reference dyes P, Q and R, whose R_f values (measured previously under the same conditions) are $R_f(\text{P}) = 0.25$, $R_f(\text{Q}) = 0.54$, $R_f(\text{R}) = 0.80$. On the chromatogram, the solvent front travels 8.0 cm from the baseline, and the unknown dye spot travels 6.4 cm. Identify the unknown dye.

$$R_f(\text{unknown}) = \frac{6.4}{8.0} = 0.80.$$

This matches reference dye **R** ($R_f = 0.80$), so the unknown dye is most likely **R**.

(!) Lỗi thường gặp: Do not confuse "**pure**" with "**clean-looking**". A solution or solid can look perfectly clear, colourless, or free of visible dirt and still be a mixture chemically — for example, clear salt water *looks* clean but is not a pure substance. Purity is established only by objective tests: a sharp, fixed melting/boiling point matching a known reference value, or a single spot on a chromatogram — never by appearance alone.

12.3 Tests for gases

H_2: burns with a squeaky "pop" when a lit splint is applied. O_2: relights a glowing splint. CO_2: turns limewater milky/cloudy ($Ca(OH)_2 + CO_2 -> CaCO_3 + H_2O$, as insoluble white $CaCO_3$ forms). NH_3: turns damp red litmus paper blue (the gas is alkaline); has a sharp, pungent smell. Cl_2: bleaches damp litmus paper, turning it white.

VN **GIẢI THÍCH TIẾNG VIỆT**

H_2 cháy kèm tiếng nổ "pop". O_2 làm que đóm còn tàn đỏ bùng cháy trở lại. CO_2 làm nước vôi trong hoá đục (tạo kết tủa trắng $CaCO_3$). NH_3 làm quỳ tím ẩm đỏ chuyển xanh (khí có tính bazơ), mùi khai đặc trưng. Cl_2 tẩy màu quỳ tím ẩm (làm quỳ mất màu, hoá trắng).

Khái niệm cốt lõi

Collecting gases: the choice of collection method depends on the gas's density and solubility in water. A gas **denser than air** (e.g. CO_2, Cl_2) is collected by **downward delivery** into an upright container. A gas **less dense than air** (e.g. H_2) is collected by **upward delivery** (downward displacement of air) into an inverted container. A gas that is **insoluble (or only slightly soluble) in water** (e.g. H_2, O_2) can be collected **over water** in an inverted, water-filled container; this method is unsuitable for very soluble gases such as NH_3, which would simply dissolve into the water instead of collecting as a gas.

VN **GIẢI THÍCH TIẾNG VIỆT**

Cách thu khí phụ thuộc vào tỉ trọng và độ tan trong nước: khí **nặng hơn không khí** (CO_2, Cl_2) thu bằng cách đẩy khí xuống (miệng bình hướng lên); khí **nhẹ hơn không khí** (H_2) thu bằng cách đẩy không khí xuống (miệng bình úp ngược); khí **ít tan trong nước** (H_2, O_2) có thể thu bằng phương pháp **đẩy nước**, nhưng cách này không dùng được cho khí tan nhiều như NH_3.

Safety notes for gas tests: the "pop" test for H_2 should only be carried out on a **small** sample of gas (e.g. collected in a small test tube), held away from the face, since larger volumes of hydrogen mixed with air can combust more violently. Tests involving Cl_2 or concentrated ammonia should be carried out in a fume cupboard, since both gases are toxic/irritating in higher concentrations. Damp litmus/indicator paper should be held *in* the gas (e.g. at the mouth of the test tube), not directly in any liquid reagent, unless the test specifically instructs otherwise.

VN **GIẢI THÍCH TIẾNG VIỆT**

Lưu ý an toàn: phép thử tiếng nổ "pop" của H_2 chỉ nên thực hiện với **lượng khí nhỏ**, cầm xa mặt, vì lượng khí lớn có thể gây nổ mạnh hơn. Các phép thử liên quan Cl_2 hoặc ammonia đặc nên thực hiện trong tủ hút khí vì đều độc/gây kích ứng ở nồng độ cao.

Ví dụ mẫu · Worked example — identifying a gas mixture

A reaction produces a gas. A lit splint held at the mouth of the test tube goes out with a squeaky pop, and the gas has no effect on damp litmus paper. A separate portion of gas is bubbled through limewater, which does not turn milky. Identify the gas, giving reasons.

The squeaky pop with a lit splint is the characteristic test for **hydrogen**, H_2. No effect on damp litmus paper rules out NH_3 (would turn it blue) and Cl_2 (would bleach it); no milkiness with limewater rules out CO_2. All observations are consistent with H_2 alone.

Khái niệm cốt lõi

Testing for water: anhydrous **copper(II) sulfate** is a white powder that turns **blue** in the presence of water, as it forms hydrated copper(II) sulfate crystals ($CuSO_4 + 5H_2O -> CuSO_4.5H_2O$). **Cobalt(II) chloride paper** is blue when dry (anhydrous) and turns **pink** in the presence of water.

These tests only show that water is *present* — they do *not* prove the water is **pure**. To confirm a liquid is pure water, its **boiling point** must be measured and shown to be exactly $100\,^{\circ}$C (and/or its freezing point exactly $0\,^{\circ}$C) at standard atmospheric pressure.

VN **GIẢI THÍCH TIẾNG VIỆT**

Bột $CuSO_4$ khan (trắng) chuyển **xanh lam** khi có nước; giấy cobalt(II) chloride khan (xanh dương) chuyển **hồng** khi có nước. Đây chỉ là phép thử cho biết **có mặt** nước, **không** chứng minh nước đó **tinh khiết** — muốn khẳng định tinh khiết phải đo nhiệt độ sôi đúng $100\,^{\circ}$C (hoặc nhiệt độ đông đặc đúng $0\,^{\circ}$C) ở áp suất chuẩn.

12.4 Tests for cations

Khái niệm cốt lõi

Aqueous **sodium hydroxide** is added **dropwise, then in excess**, to a solution of the unknown cation; the colour of any precipitate, and whether it dissolves in excess, identifies the cation. Chemically, most transition-metal and Group III cations form an insoluble metal hydroxide precipitate when they meet hydroxide ions in solution — a simple **precipitation (double decomposition) reaction** — so the appearance (or absence) of a precipitate, and its colour, is diagnostic of which metal ion is present.

Cation	With NaOH, added dropwise	With NaOH, in excess
Ca^{2+}	white precipitate	remains, insoluble in excess
Cu^{2+}	blue precipitate	remains, insoluble in excess
Fe^{2+}	green precipitate	remains, insoluble in excess (may darken on standing in air)
Fe^{3+}	red-brown precipitate	remains, insoluble in excess
Al^{3+}	white precipitate	**dissolves** to a colourless solution
Zn^{2+}	white precipitate	**dissolves** to a colourless solution
NH_4^+	no precipitate	warming releases NH_3 gas (damp red litmus → blue)

Cation test summary. Note: Li^+, Na^+ and K^+ give **no precipitate** with NaOH at all (their hydroxides are soluble) — these Group I ions are identified instead by their flame colours.

VN **GIẢI THÍCH TIẾNG VIỆT**

Nhỏ từ từ rồi cho dư dung dịch NaOH: Ca^{2+} kết tủa trắng, Cu^{2+} kết tủa xanh lam, Fe^{2+} kết tủa xanh lục (lục nhạt), Fe^{3+} kết tủa nâu đỏ — cả bốn đều **không tan** khi cho dư NaOH. Riêng Al^{3+} và Zn^{2+} kết tủa trắng nhưng **tan** khi dư NaOH, tạo dung dịch không màu (hydroxide lưỡng tính). NH_4^+ không tạo kết tủa; đun nóng với NaOH sinh khí NH_3 làm xanh quỳ tím ẩm. Các ion nhóm I (Li^+, Na^+, K^+) không kết tủa với NaOH vì hydroxide của chúng tan tốt trong nước — phải dùng thử ngọn lửa để nhận biết.

Ionic equations for the NaOH precipitation reactions: $Ca^{2+} + 2OH^- -> Ca(OH)_2$; $Cu^{2+} + 2OH^- -> Cu(OH)_2$; $Fe^{2+} + 2OH^- -> Fe(OH)_2$; $Fe^{3+} + 3OH^- -> Fe(OH)_3$; $Al^{3+} + 3OH^- -> Al(OH)_3$; $Zn^{2+} + 2OH^- -> Zn(OH)_2$. In each case the number of OH^- ions matches the charge on the cation.

Ví dụ mẫu · Worked example

A colourless solution forms a white precipitate with NaOH solution, which *dissolves* when excess NaOH is added, giving a colourless solution. Identify the possible cation(s), and describe a further test to distinguish between them.

Both Al^{3+} and Zn^{2+} give a white precipitate that dissolves in excess NaOH — the NaOH test alone cannot distinguish them, since both hydroxides are **amphoteric** (they react with excess

strong alkali to form a soluble aluminate/zincate ion).

Instead, add aqueous **ammonia**, dropwise then in excess, to a fresh sample: $Al(OH)_3$ forms as a white precipitate that stays **insoluble** even in excess ammonia. $Zn(OH)_2$ also forms first as a white precipitate, but **redissolves** in excess ammonia, forming a soluble, colourless complex ion, the tetraamminezinc(II) ion $[Zn(NH_3)_4]^{2+}$. (Aluminium does not form an ammine complex, which is why $Al(OH)_3$ does not redissolve.) So: precipitate dissolves in excess ammonia $\Rightarrow$ Zn^{2+}; precipitate remains insoluble in excess ammonia $\Rightarrow$ Al^{3+}.

Khái niệm cốt lõi (Supplement)

The reason $Al(OH)_3$ and $Zn(OH)_2$ dissolve in excess NaOH is that both are **amphoteric hydroxides** — they can react with excess strong alkali as well as with acid. In excess OH^-, they form soluble complex ions: $Al(OH)_3 + OH^- -> [Al(OH)_4]^-$ (colourless aluminate ion) and $Zn(OH)_2 + 2OH^- -> [Zn(OH)_4]^{2-}$ (colourless zincate ion). This is why the NaOH test alone cannot distinguish Al^{3+} from Zn^{2+}, and why the ammonia test (which Al^{3+} does not respond to in the same way) is needed.

VN **GIẢI THÍCH TIẾNG VIỆT**

$Al(OH)_3$ và $Zn(OH)_2$ tan trong NaOH dư vì đều là **hydroxide lưỡng tính**, phản ứng được với cả axit lẫn kiềm mạnh dư, tạo ion phức tan: $[Al(OH)_4]^-$ (aluminate) và $[Zn(OH)_4]^{2-}$ (zincate), đều không màu. Đây là lý do phép thử NaOH không thể phân biệt Al^{3+} và Zn^{2+}, cần dùng thêm phép thử ammonia.

Ví dụ mẫu · Worked example

Describe how NaOH solution can be used to distinguish between separate solutions of iron(II) sulfate and iron(III) sulfate.

Adding NaOH solution to iron(II) sulfate gives a **green** precipitate ($Fe(OH)_2$), insoluble in excess; adding NaOH to iron(III) sulfate gives a **red-brown** precipitate ($Fe(OH)_3$), also insoluble in excess. Neither redissolves, so the distinguishing feature is the precipitate **colour** alone (green for Fe^{2+}, red-brown for Fe^{3+}).

12.4.1 Flame tests

Khái niệm cốt lõi

Since Group I metal ions (Li^+, Na^+, K^+) give no precipitate with NaOH, they — along with Ca^{2+} and Cu^{2+} — can be identified instead by a **flame test**. **Procedure**: clean a nichrome (or platinum) wire by dipping it into concentrated hydrochloric acid and holding it in the hottest, non-luminous part of a Bunsen flame until it imparts no colour; dip the clean wire into a little of the solid (or a paste made with a drop of concentrated HCl); hold the wire at the edge of the flame and observe the flame colour immediately, as it may only last briefly.

Flame test colours: Li^+ red (crimson); Na^+ persistent yellow/orange; K^+ lilac; Ca^{2+} brick-red/orange-red; Cu^{2+} blue-green (green).

VN **GIẢI THÍCH TIẾNG VIỆT**

Thử ngọn lửa: làm sạch dây bạch kim/nichrome bằng cách nhúng vào HCl đặc rồi hơ trên ngọn lửa đến khi không còn màu, sau đó nhúng dây vào mẫu rắn (hoặc hồ với 1 giọt HCl đặc), đưa vào rìa ngọn lửa Bunsen và quan sát ngay màu ngọn lửa. Màu đặc trưng: Li^+ đỏ, Na^+ vàng cam, K^+ tím hoa cà (lilac), Ca^{2+} đỏ gạch, Cu^{2+} xanh lục lam.

Sodium's yellow/orange flame colour is extremely intense and persistent, and can easily mask or contaminate the result of a flame test on a different sample if the test wire is not cleaned thoroughly between tests — even a tiny trace of a sodium compound left on the wire can produce a strong yellow flame that swamps a weaker or more subtle colour from another cation.

(!) Lỗi thường gặp: It is easy to mix up which NaOH-precipitate colour belongs to which cation. Anchor them with the colour of the metal itself where possible: Cu^{2+} (blue precipitate) matches the familiar blue of copper compounds; Fe^{2+} ($+2$, "ferr*ous*") gives a duller **green**; Fe^{3+} ($+3$, "ferr*ic*") gives a stronger **red-brown** (rust colour, as Fe^{3+} is literally the ion in rust). Al^{3+} and Zn^{2+} are the two that *redissolve* in excess NaOH — remembering this pair ("amphoteric", both dissolve) prevents them being confused with Ca^{2+}, whose white precipitate does *not* redissolve.

12.5 Tests for anions

Khái niệm cốt lõi

Each anion is identified by adding a specific acid or reagent and observing effervescence, gas evolved, or a precipitate.

Anion	Test	Observation
Carbonate CO_3^{2-}	add dilute acid (e.g. HCl)	effervescence; gas turns limewater milky (CO_2)
Sulfate SO_4^{2-}	add dilute HCl, then $BaCl_2$(aq)	white precipitate ($BaSO_4$)
Chloride Cl^-	add dilute HNO_3, then $AgNO_3$(aq)	white precipitate (AgCl)
Bromide Br^-	add dilute HNO_3, then $AgNO_3$(aq)	cream precipitate (AgBr)
Iodide I^-	add dilute HNO_3, then $AgNO_3$(aq)	yellow precipitate (AgI)

Anion test summary. **(Supplement)** The three silver halide precipitates can be told apart further by their solubility in ammonia (see worked example below): AgCl dissolves in **dilute** ammonia; AgBr dissolves only in **concentrated** ammonia; AgI is insoluble even in concentrated ammonia.

VN **GIẢI THÍCH TIẾNG VIỆT**

Carbonate: thêm axit loãng → sủi bọt khí, khí làm đục nước vôi trong (CO_2). Sulfate: thêm HCl loãng rồi $BaCl_2$ → kết tủa trắng $BaSO_4$. Halide (Cl^-, Br^-, I^-): thêm HNO_3 loãng rồi $AgNO_3$ → kết tủa trắng (Cl^-), kem/vàng nhạt (Br^-), vàng (I^-). **(Supplement)** Có thể phân biệt sâu hơn ba kết tủa bạc halide này bằng độ tan trong dung dịch ammonia: AgCl tan trong ammonia **loãng**; AgBr chỉ tan trong ammonia **đặc**; AgI không tan dù trong ammonia đặc.

Ionic equations for the anion precipitation reactions: $CO_3^{2-} + 2H^+ -> H_2O + CO_2$; $Ba^{2+} + SO_4^{2-} -> BaSO_4$; $Ag^+ + Cl^- -> AgCl$; $Ag^+ + Br^- -> AgBr$; $Ag^+ + I^- -> AgI$. When writing the full equation with state symbols, the precipitate is labelled (s), the ions forming it (aq), and any gas released (g) — e.g. $Ba^{2+}(aq) + SO_4^{2-}(aq) -> BaSO_4(s)$.

Ví dụ mẫu · Worked example (Supplement)

Three unknown solutions each give a precipitate with dilute nitric acid followed by silver nitrate solution, but the precipitate colours (white, cream, pale yellow) are hard to tell apart confidently by eye alone. Describe a further test using aqueous ammonia to confirm the identity of each halide.

Split each precipitate into two portions. Add **dilute** ammonia to the first portion of each: the precipitate that **dissolves** in dilute ammonia is AgCl, confirming Cl^-. For the two precipitates that do *not* dissolve in dilute ammonia, add **concentrated** ammonia to the second portion: the one that now **dissolves** is AgBr, confirming Br^-; the one that remains **insoluble** even in concentrated ammonia is AgI, confirming I^-.

(!) Lỗi thường gặp: The sulfate test needs **both** reagents in the correct order — dilute HCl *first*, then $BaCl_2$ solution. Adding $BaCl_2$ alone is not conclusive, because Ba^{2+} also forms a white precipitate with carbonate ions ($BaCO_3$). The dilute HCl is added first specifically to react away (and rule out) any carbonate — if the acid causes effervescence, carbonate was present and must be accounted for; only once no further effervescence occurs can a white precipitate with $BaCl_2$ be confidently attributed to sulfate. The same logic applies to the halide test: dilute HNO_3 is added before $AgNO_3$ to remove interference from carbonate (which would otherwise also give a precipitate with silver ions). Also note *which* acid is used matters: dilute **hydrochloric** acid (not sulfuric acid) is used before $BaCl_2$ in the sulfate test, because sulfuric acid would itself introduce SO_4^{2-} ions and cause a false positive; conversely, dilute **nitric** acid (not hydrochloric acid) is used before $AgNO_3$ in the halide test, because hydrochloric acid would itself introduce Cl^- ions and cause a false precipitate.

12.6 Systematic qualitative analysis

Khái niệm cốt lõi

Before any chemical test, the **colour of the solid or solution** already narrows down the possibilities. A **colourless** solution rules out the coloured transition-metal ions in the standard test list (Cu^{2+}, Fe^{2+}, Fe^{3+}), leaving Ca^{2+}, Al^{3+}, Zn^{2+}, NH_4^+ or a Group I ion as candidates. A **blue** solution strongly suggests Cu^{2+}; a **pale green** solution suggests Fe^{2+}; a **yellow/orange-brown** solution suggests Fe^{3+}. This is a quick first clue, not a substitute for the confirmatory NaOH test.

VN **GIẢI THÍCH TIẾNG VIỆT**

Trước khi làm bất kỳ phép thử hoá học nào, **màu sắc** của mẫu rắn/dung dịch đã cho manh mối đầu tiên: dung dịch **không màu** loại trừ các ion kim loại chuyển tiếp có màu (Cu^{2+}, Fe^{2+}, Fe^{3+}); dung dịch **xanh lam** gợi ý Cu^{2+}; **xanh lục nhạt** gợi ý Fe^{2+}; **vàng/nâu cam** gợi ý Fe^{3+}. Đây chỉ là gợi ý ban đầu, vẫn cần làm phép thử NaOH để xác nhận.

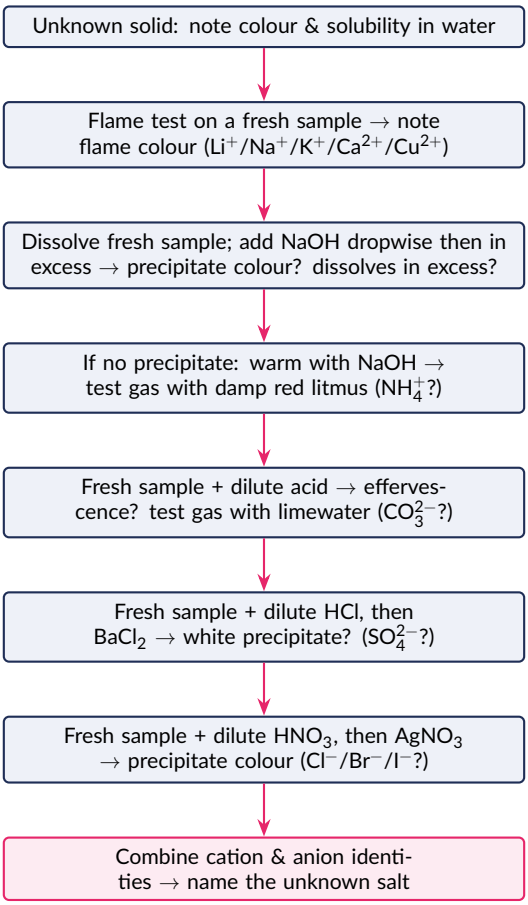
Khái niệm cốt lõi

To identify an unknown salt, cation and anion tests are combined into an ordered strategy, always using a **fresh sample** for each test (since some tests, like adding acid, consume or alter the sample):

1. Note physical observations: colour, state, solubility in water.
2. **Flame test** on a solid sample (identifies Group I ions and Ca^{2+}/Cu^{2+} directly; no coloured

flame narrows down the remaining possibilities).

3. Dissolve a fresh sample and add **NaOH dropwise, then in excess**, noting any precipitate colour and whether it redissolves.
4. If no precipitate formed, **warm** with NaOH and test any gas evolved with damp red litmus paper (confirms NH_4^+).
5. On a fresh sample, add **dilute acid** and test any gas with limewater (confirms carbonate).
6. On a fresh sample, add **dilute HCl then** $BaCl_2$ (tests for sulfate).
7. On a fresh sample, add **dilute** HNO_3 **then** $AgNO_3$ (tests for a halide).
8. Combine the cation and anion identities to name the unknown salt.



Systematic qualitative analysis: work through cation tests, then anion tests, using a fresh sample each time, and combine the results to name the salt.

VN **GIẢI THÍCH TIẾNG VIỆT**

Chiến lược phân tích định tính: quan sát vật lý → thử ngọn lửa → NaOH (nhỏ giọt rồi dư) → nếu không kết tủa thì đun với NaOH thử khí NH_4^+ → thử axit loãng cho carbonate → HCl loãng rồi $BaCl_2$ cho sulfate → HNO_3 loãng rồi $AgNO_3$ cho halide → kết hợp kết quả cation và anion để gọi tên muối. Luôn dùng **mẫu mới** cho mỗi phép thử.

Ví dụ mẫu · Worked example — identifying an unknown white solid

An unknown white crystalline solid X is analysed. A flame test gives a **lilac** flame. A fresh sample is dissolved in water and NaOH solution is added dropwise, then in excess: **no precipitate** forms at any point. A separate fresh sample is treated with dilute hydrochloric acid: vigorous **effervescence** occurs, and the gas produced turns limewater **milky**. Identify X.

The lilac flame indicates K^+. No precipitate with NaOH (even in excess) is consistent with a Group I cation, since potassium hydroxide is soluble — this rules out Ca^{2+}, Cu^{2+}, Fe^{2+}, Fe^{3+}, Al^{3+} and Zn^{2+}, all of which give a precipitate. Effervescence with dilute acid, with the gas turning limewater milky, confirms CO_2 is released, so the anion is carbonate, CO_3^{2-}.

X is potassium carbonate, K_2CO_3.

Ví dụ mẫu · Worked example — identifying an unknown salt

An unknown salt Y is a white solid, soluble in water to give a colourless solution. Adding NaOH solution dropwise produces a white precipitate, which **dissolves** on adding excess NaOH to give a colourless solution. On a fresh sample, aqueous ammonia is added dropwise then in excess: a white precipitate forms and remains **insoluble** even in excess ammonia. On another fresh sample, dilute nitric acid is added followed by silver nitrate solution: a **white** precipitate forms. Identify Y.

The white NaOH precipitate dissolving in excess narrows the cation to Al^{3+} or Zn^{2+}. The ammonia test resolves this: since the precipitate stays *insoluble* in excess ammonia, the cation is Al^{3+} (a Zn^{2+} precipitate would have redissolved in excess ammonia). The white precipitate with dilute HNO_3 then $AgNO_3$ confirms Cl^- (a cream or yellow precipitate would instead indicate Br^- or I^-).

Y is aluminium chloride, $AlCl_3$.

Ví dụ mẫu · Worked example — combining colour, cation and anion tests

A pale blue crystalline solid Z dissolves in water to give a blue solution. Adding NaOH solution dropwise gives a blue precipitate, insoluble in excess. On a fresh sample, dilute hydrochloric acid is added (no effervescence), followed by barium chloride solution: a white precipitate forms. Identify Z.

The pale blue colour of the solid and solution, together with a blue precipitate with NaOH that is insoluble in excess, identifies the cation as Cu^{2+}. No effervescence with dilute HCl rules out carbonate; the white precipitate on adding $BaCl_2$ confirms sulfate, SO_4^{2-}.

Z is copper(II) sulfate, $CuSO_4$ (note: as pentahydrate crystals, $CuSO_4.5H_2O$, this compound is characteristically blue — consistent with the colour observed even before any test is carried out).

Observation	Most likely ion	Confirming test
Lilac flame	K^+	no NaOH precipitate
Yellow/orange flame	Na^+	no NaOH precipitate
Red (crimson) flame	Li^+	no NaOH precipitate
Brick-red flame, white NaOH ppt (insoluble in excess)	Ca^{2+}	flame test + NaOH
Blue-green flame, blue NaOH ppt (insoluble in excess)	Cu^{2+}	flame test + NaOH
Green NaOH ppt, insoluble in excess	Fe^{2+}	NaOH
Red-brown NaOH ppt, insoluble in excess	Fe^{3+}	NaOH
White NaOH ppt, dissolves in excess; insoluble in excess NH_3	Al^{3+}	NaOH + ammonia
White NaOH ppt, dissolves in excess; dissolves in excess NH_3	Zn^{2+}	NaOH + ammonia
No precipitate; gas turns litmus blue on warming with NaOH	NH_4^+	NaOH (warm)
Effervescence with acid; gas turns limewater milky	CO_3^{2-}	dilute acid
White ppt with dilute HCl then $BaCl_2$	SO_4^{2-}	HCl + $BaCl_2$
White ppt with dilute HNO_3 then $AgNO_3$	Cl^-	HNO_3 + $AgNO_3$
Cream ppt with dilute HNO_3 then $AgNO_3$	Br^-	HNO_3 + $AgNO_3$
Yellow ppt with dilute HNO_3 then $AgNO_3$	I^-	HNO_3 + $AgNO_3$

Master quick-reference: matching a single key observation to the most likely ion, and the test that confirms it.

12.7 Practice

Bài tập luyện tập

Which gas turns limewater milky/cloudy?

(A) Hydrogen
(C) Carbon dioxide
(B) Oxygen
(D) Ammonia

Lời giải chi tiết

CO_2 reacts with the calcium hydroxide in limewater to form insoluble white $CaCO_3$, seen as milky cloudiness. **(C)**.

Bài tập luyện tập

What flame colour is produced by potassium ions?

(A) Yellow/orange
(C) Lilac
(B) Brick-red
(D) Blue-green

Lời giải chi tiết

Potassium gives a **lilac** flame (sodium gives yellow/orange; calcium gives brick-red; copper gives blue-green). **(C)**.

Bài tập luyện tập

On a chromatogram, a spot travels 3.9 cm from the baseline and the solvent front travels 6.0 cm. Calculate the R_f value.

Lời giải chi tiết

$$R_f = \frac{3.9}{6.0} = 0.65.$$

Bài tập luyện tập

A mixture of iron filings and sulfur powder is to be separated using a physical method (no reaction). Suggest a suitable method and explain why it works. (Iron is magnetic; sulfur is not — this is a physical separation, distinct from filtration.)

Lời giải chi tiết

A magnet can be passed through/over the mixture: the iron filings are attracted and picked up, leaving the sulfur behind. This works because the separation exploits a genuine physical property difference (magnetism) rather than solubility or particle size, so no filtration, evaporation, or chemical reaction is needed.

Bài tập luyện tập

Explain why, when crystallising copper(II) sulfate from solution, the solution should not be evaporated all the way to dryness.

Lời giải chi tiết

Evaporating fully to dryness risks trapping any dissolved impurities inside the solid (they have nowhere else to go once all the water is gone) and can overheat/decompose the hydrated crystals. Instead, the solution should be evaporated only until saturated, then allowed to cool slowly so that pure crystals grow, leaving impurities behind in the small amount of remaining solution, which is removed by filtration.

Bài tập luyện tập

Describe the function of the thermometer in simple distillation, and explain why its bulb must be positioned level with the side-arm rather than deep in the liquid.

Lời giải chi tiết

The thermometer measures the temperature of the **vapour** as it leaves the flask, which should match the boiling point of the substance being collected. If the bulb were immersed in the liquid instead, it would measure the temperature of the boiling mixture (which can rise as the more volatile component is used up), not the temperature of what is actually distilling over — so positioning it level with the side-arm ensures the reading reflects the vapour about to be condensed and collected.

Bài tập luyện tập

State the purpose of the glass beads (or rings) packed into a fractionating column.

Lời giải chi tiết

They provide a large surface area on which rising vapour can repeatedly condense and re-evaporate as it moves up the column. Each condensation–evaporation cycle enriches the vapour further in the more volatile (lower boiling point) component, allowing liquids with close boiling points to be separated efficiently.

Bài tập luyện tập (Supplement)

A student has a mixture of oil and water. Suggest the most suitable apparatus to separate them, and briefly describe the procedure.

Lời giải chi tiết

A **separating funnel** is used, since oil and water are immiscible. Pour the mixture in and allow it to settle into two layers (water, being denser, sits below the oil). Open the tap to run the lower (water) layer out into a container, closing it just before the oil–water boundary reaches the tap, then pour the oil out of the top separately.

Bài tập luyện tập

A pure liquid has a boiling point of exactly $100\,^{\circ}$C, while an impure sample of the same liquid is found to boil over a range starting at $101\,^{\circ}$C. Comment on this observation.

Lời giải chi tiết

This is the reverse pattern from melting point (impurities usually *raise* the observed boiling range for volatile solvents like water with a non-volatile dissolved solute, as well as broadening it into a range rather than one sharp value) — the key diagnostic feature of impurity here is that boiling occurs over a spread of temperatures rather than sharply at one fixed value, not simply whether the range is higher or lower.

Bài tập luyện tập

Describe how NaOH solution can be used to distinguish between separate solutions of copper(II) sulfate and iron(II) sulfate.

Lời giải chi tiết

Adding NaOH solution to copper(II) sulfate gives a **blue** precipitate ($Cu(OH)_2$), insoluble in excess. Adding NaOH to iron(II) sulfate gives a **green** precipitate ($Fe(OH)_2$), also insoluble in excess. The precipitate colour (blue vs green) distinguishes the two cations.

Bài tập luyện tập

A colourless solution gives a white precipitate with NaOH solution that does *not* dissolve in excess NaOH, and no flame colour is observed. Which cation could this be?

(A) Cu^{2+}
(B) Ca^{2+}
(C) Fe^{3+}
(D) Al^{3+}

Lời giải chi tiết

Cu^{2+} gives a blue precipitate (not white) and Fe^{3+} gives a red-brown precipitate (not white), so both are ruled out. Al^{3+} gives a white precipitate but it *dissolves* in excess NaOH, so it is also ruled out. Ca^{2+} gives a white precipitate that is insoluble in excess NaOH, and calcium has no distinctive flame colour test used at this level (unlike Cu^{2+}). **(B)**.

Bài tập luyện tập

Describe a chemical test that distinguishes a solution containing Al^{3+} ions from one containing Zn^{2+} ions.

Lời giải chi tiết

Add aqueous ammonia dropwise, then in excess, to each solution. Both initially give a white precipitate (the hydroxide). With **excess** ammonia, the Al^{3+} precipitate remains insoluble, while the Zn^{2+} precipitate redissolves to a colourless solution (forming the soluble complex ion $[Zn(NH_3)_4]^{2+}$).

Bài tập luyện tập

A solution turns damp red litmus paper blue when warmed with NaOH solution, but forms no visible precipitate at any stage. Which ion is present?

(A) Ca^{2+}
(B) NH_4^+
(C) Fe^{2+}
(D) Zn^{2+}

Lời giải chi tiết

Ammonia gas (NH_3) is alkaline and turns damp red litmus paper blue; it is released on warming a solution containing NH_4^+ with NaOH, and no precipitate is formed with ammonium ions. **(B)**.

Bài tập luyện tập

A white precipitate forms when dilute hydrochloric acid, then barium chloride solution, are added to an unknown solution. This indicates the presence of which anion?

(A) Chloride
(B) Carbonate
(C) Sulfate
(D) Nitrate

Lời giải chi tiết

Ba^{2+} reacts with SO_4^{2-} to form insoluble white $BaSO_4$; the dilute HCl first rules out carbonate (which would effervesce, not give a lasting precipitate with $BaCl_2$ alone). **(C)**.

Bài tập luyện tập

Explain how melting point data can be used to show whether a solid sample is pure.

Lời giải chi tiết

Melt the sample and record the temperature range over which it melts. A **pure** substance melts sharply at one fixed, known temperature. An **impure** sample melts over a broader **range**, typically starting below the true melting point of the pure substance — the wider the range and the lower the starting temperature, the more impure the sample.

Bài tập luyện tập

A solution of an unknown halide is treated with dilute nitric acid, then silver nitrate solution, producing a cream precipitate. Which halide ion is present?

(A) Chloride
(B) Bromide
(C) Iodide
(D) Fluoride

Lời giải chi tiết

Chloride gives a white precipitate, bromide gives a **cream** precipitate, and iodide gives a yellow precipitate with silver nitrate (fluoride does not give a precipitate with $AgNO_3$ under these conditions and is not tested this way). **(B)**.

Bài tập luyện tập (Supplement)

An unknown silver halide precipitate dissolves when treated with concentrated ammonia, but does not dissolve in dilute ammonia. Which halide ion was originally present?

(A) Chloride
(B) Bromide
(C) Iodide
(D) None — all silver halides dissolve in ammonia

Lời giải chi tiết

AgCl dissolves even in dilute ammonia; AgI does not dissolve even in concentrated ammonia. Only AgBr shows this intermediate behaviour — insoluble in dilute ammonia, but soluble in concentrated ammonia. So the original ion was **bromide**. **(B)**.

Bài tập luyện tập

A white solid is thought to be either calcium carbonate or calcium sulfate. Describe a test to distinguish between them.

Lời giải chi tiết

Add dilute hydrochloric acid to a sample of each. Calcium carbonate effervesces, releasing CO_2 gas (which turns limewater milky), and dissolves. Calcium sulfate does not effervesce with dilute HCl (calcium sulfate is only slightly soluble and does not react with dilute acid in this way).

Bài tập luyện tập

A student wants to confirm that a colourless liquid is pure water rather than merely containing some water. Describe the test they should carry out, and explain why anhydrous copper(II) sulfate alone is not sufficient.

Lời giải chi tiết

The student should measure the **boiling point** of the liquid and confirm it is exactly $100\,^{\circ}\text{C}$ at standard atmospheric pressure (a sharp, fixed value, not a range). Anhydrous copper(II) sulfate turning blue only shows that *some* water is present in the liquid — it would turn blue even if

the liquid were an aqueous solution containing dissolved impurities, so it cannot confirm the water itself is pure.

Bài tập luyện tập

Describe how you would carry out a flame test on a solid sample, and state one precaution needed for a reliable result.

Lời giải chi tiết

Clean a nichrome or platinum wire by dipping it in concentrated hydrochloric acid and heating it in a non-luminous Bunsen flame until it produces no colour. Dip the clean wire into the solid sample (or a paste of the solid with a drop of concentrated HCl), then hold it at the edge of the flame and observe the colour immediately. Precaution: the wire must be thoroughly cleaned before each test (and between different samples), otherwise a lingering trace of a previous sample (especially strongly-coloured sodium) could contaminate the result.

Bài tập luyện tập

A solution gives a white precipitate with NaOH (dropwise) that remains insoluble in excess. A separate fresh sample gives no coloured flame. Which cation is most consistent with these two results?

(A) Al^{3+} **(C)** Cu^{2+}

(B) Ca^{2+} **(D)** Fe^{3+}

Lời giải chi tiết

Cu^{2+} would give a blue flame test colour and a blue precipitate (both ruled out); Fe^{3+} gives a red-brown precipitate (ruled out); Al^{3+} gives a white precipitate that *dissolves* in excess (ruled out). Ca^{2+} gives a white precipitate insoluble in excess NaOH, and calcium's brick-red flame colour can sometimes be faint/hard to observe depending on conditions, but among the options only Ca^{2+}'s NaOH behaviour matches exactly. **(B)**.

Bài tập luyện tập

Describe a test that would confirm the presence of chlorine gas in a sample, distinguishing it from other common gases.

Lời giải chi tiết

Hold a piece of damp litmus paper in the gas: chlorine **bleaches** the litmus paper, turning it white. This is distinct from NH_3 (turns damp red litmus blue, not bleached), CO_2 (no effect on litmus; tested with limewater instead), and H_2/O_2 (tested with a lit/glowing splint, not litmus).

Bài tập luyện tập

An unknown gas relights a glowing splint. A second unknown gas gives a squeaky pop with a lit splint. Identify both gases.

Lời giải chi tiết

The gas that relights a glowing splint is **oxygen**, O_2 (a test for a gas that supports combustion). The gas that gives a squeaky pop with a lit splint is **hydrogen**, H_2 (the pop is the rapid combustion of hydrogen with oxygen in the air).

Bài tập luyện tập

Outline, in order, the sequence of tests you would perform to identify an unknown white solid that is suspected to be a Group I metal salt.

Lời giải chi tiết

(1) Note the solid is white and crystalline. (2) Carry out a flame test on a fresh sample to identify the metal ion (e.g. yellow for Na^+, lilac for K^+). (3) Dissolve a fresh sample in water and add NaOH dropwise then in excess — expect **no precipitate** at any point, consistent with a Group I cation (whose hydroxide is soluble). (4) On separate fresh samples, test for the anion: dilute acid + limewater test for carbonate; dilute HCl then $BaCl_2$ for sulfate; dilute HNO_3 then $AgNO_3$ for a halide. (5) Combine the flame colour (cation) with the anion test result to name the salt.

Bài tập luyện tập

An unknown solid Z gives a brick-red flame test and forms a white precipitate with NaOH solution that does not redissolve in excess. On a fresh sample, dilute hydrochloric acid produces vigorous effervescence, and the gas turns limewater milky. Identify Z.

Lời giải chi tiết

Brick-red flame indicates Ca^{2+}; a white NaOH precipitate insoluble in excess is also consistent with Ca^{2+} (ruling out Al^{3+}/Zn^{2+}, whose precipitates would dissolve). Effervescence with dilute acid, gas turning limewater milky, confirms CO_3^{2-}. **Z is calcium carbonate,** $CaCO_3$**.**

Bài tập luyện tập

An unknown solid W dissolves in water to a pale green solution. NaOH solution added dropwise gives a green precipitate, insoluble in excess. A fresh sample treated with dilute nitric acid then silver nitrate gives a yellow precipitate. Identify W.

Lời giải chi tiết

A pale green solution and a green NaOH precipitate, insoluble in excess, indicate Fe^{2+}. A yellow precipitate with dilute HNO_3 then $AgNO_3$ indicates iodide, I^-. **W is iron(II) iodide,** FeI_2**.**

Bài tập luyện tập

An unknown solid gives no flame colour and no precipitate with NaOH solution even after warming (no gas evolved either). A fresh sample with dilute HCl then $BaCl_2$ gives a white precipitate. Suggest the identity of the salt, explaining your reasoning.

Lời giải chi tiết

No flame colour and no precipitate (or gas) with NaOH rules out all the cations in the standard test table *except* that it is still consistent with a Group I cation whose flame colour test may have been inconclusive, or with an ion outside this test scheme; commonly at this level such a result together with a positive sulfate test (white precipitate with dilute HCl then $BaCl_2$) is interpreted as sodium sulfate, Na_2SO_4 — sodium's yellow flame is sometimes missed if the flame is not observed carefully, so a repeat flame test is recommended before finalising the identification.

Bài tập luyện tập

Explain why a fresh sample of the unknown solid must be used for each individual test in a systematic qualitative analysis, rather than re-using the solution from a previous test.

Lời giải chi tiết

Many tests consume or chemically alter the sample — for example, adding acid to test for carbonate destroys the carbonate ion (releasing it as CO_2 gas) and changes the solution's composition, while adding NaOH changes the pH and precipitates the cation. Re-using an already-tested sample for a further test could give a false result (e.g. a precipitate already removed, or excess reagent from the previous test interfering), so a fresh, untouched sample is needed for each independent test.

Bài tập luyện tập

A student is given an unknown salt and told it is either magnesium chloride or aluminium chloride (both give a white precipitate with NaOH). Aqueous ammonia is added to a fresh sample, dropwise then in excess, and the precipitate does not dissolve at any point. What can the student conclude?

Lời giải chi tiết

This test alone does not fully distinguish them, since neither $Mg(OH)_2$ nor $Al(OH)_3$ dissolves in excess ammonia (ammonia only distinguishes Al^{3+} from Zn^{2+}, not from Mg^{2+}). To distinguish Mg^{2+} from Al^{3+} specifically, the student should instead retest with **excess NaOH**: $Al(OH)_3$ dissolves in excess NaOH (colourless solution), while $Mg(OH)_2$ remains insoluble even in excess NaOH.

Bài tập luyện tập

Write the ionic equation for the reaction between iron(III) ions and hydroxide ions, and state the colour of the precipitate formed.

Lời giải chi tiết

$Fe^{3+} + 3OH^- -> Fe(OH)_3$. The precipitate is **red-brown**.

Bài tập luyện tập

A mixture consists of a soluble salt dissolved in ethanol (not water). Suggest how the dissolved salt could be recovered as a dry solid, and explain your choice of method.

Lời giải chi tiết

Simple **distillation** (or careful evaporation) can be used to remove the ethanol solvent, leaving the salt behind, since the salt is not volatile while ethanol boils at a comparatively low temperature ($78\,^{\circ}$C). Because ethanol is flammable, it should be heated using an electric heating mantle or a water bath rather than a naked Bunsen flame.

Bài tập luyện tập

Explain why the thermometer bulb in a simple distillation should never be allowed to dip into the liquid in the flask.

Lời giải chi tiết

If immersed in the liquid, the thermometer would record the temperature of the boiling *mixture* in the flask (which rises over time as the more volatile component is removed) rather than the temperature of the **vapour** passing into the condenser — giving a misleading reading that no longer corresponds to the substance actually being collected.

Bài tập luyện tập

A pure solid has a known melting point of $132\,^{\circ}$C. Describe the practical steps used to measure the melting point of an unknown sample suspected to be this solid.

Lời giải chi tiết

Pack a small amount of the dry unknown solid into the sealed end of a capillary tube and attach it to a thermometer. Immerse both in an oil bath (or Thiele tube) and heat slowly and evenly, watching the sample closely. Record the temperature at which the solid first starts to melt and the temperature at which it has completely melted. If both temperatures coincide at $132\,^{\circ}$C, the sample is likely pure; a range, especially one starting below $132\,^{\circ}$C, indicates impurity.

Bài tập luyện tập

Suggest a suitable separation method for each of the following, giving one reason: (a) removing dust (insoluble solid) from a sample of river water; (b) obtaining dry crystals of copper(II) sulfate from its solution; (c) separating hexane and octane, two miscible liquids with different boiling points.

Lời giải chi tiết

(a) **Filtration** — the dust is an insoluble solid suspended in a liquid, so filter paper retains it as the residue while clean water passes through as the filtrate.
(b) **Crystallisation** — copper(II) sulfate is a soluble solid; evaporating the solution to saturation and then cooling slowly grows pure crystals, which are filtered, washed and dried.
(c) **Fractional distillation** — the two liquids are miscible with different boiling points, so a fractionating column allows repeated evaporation–condensation to separate the more volatile liquid first.

Bài tập luyện tập

After crystallising a solid product, a student finds its melting point still melts over a range wider than the pure literature value. Suggest how the student could improve the purity of the product.

Lời giải chi tiết

The student should **recrystallise** the product: redissolve it in the minimum volume of hot solvent, filter the hot solution to remove any insoluble impurity, allow it to cool slowly so pure crystals grow (leaving soluble impurities behind in the mother liquor), then filter, wash with a little cold solvent, and dry. Repeating this process (if needed) narrows the melting point range further towards the pure literature value.

Bài tập luyện tập

A colourless solid dissolves in water to give a deep blue solution. Suggest, before doing any further test, which cation is most likely present, and state the test that would confirm this.

Lời giải chi tiết

A deep blue solution strongly suggests Cu^{2+}. This can be confirmed by adding NaOH solution dropwise: Cu^{2+} gives a **blue** precipitate that remains insoluble even in excess NaOH.

Bài tập luyện tập

Explain the difference between how a pure liquid and an impure liquid (e.g. a solution) behave when their boiling temperature is monitored over time as they boil.

Lời giải chi tiết

A **pure** liquid boils at one constant, sharp temperature that does not change while boiling continues. An **impure** liquid (e.g. a solution of a non-volatile solute, or a mixture of two volatile liquids) boils over a **rising range**: as the more volatile component distils away, the composition of the remaining liquid changes, so its boiling point drifts upward over time rather than staying fixed.

Bài tập luyện tập

State the purpose of anti-bumping granules, and explain why they must be added *before* heating begins, not afterwards.

Lời giải chi tiết

Anti-bumping granules release a steady stream of small bubbles as the liquid heats, promoting smooth, even boiling and preventing violent "bumping". They must be added before heating starts because dropping them into an already-hot (or already-boiling) liquid can itself trigger a sudden, dangerous release of bubbles and spattering of hot liquid.

Bài tập luyện tập

Explain why the origin (starting spot) on a paper chromatogram must be marked *above* the level of the solvent in the container, not below it.

Lời giải chi tiết

If the spot were below the solvent surface (submerged), the sample would dissolve directly into the bulk solvent and disperse/wash away, rather than being carried steadily up the paper as the solvent front rises past it. Keeping the origin above the solvent level ensures the mixture is separated as intended, spreading into distinct spots as the solvent moves up the paper.

Bài tập luyện tập

Using the master quick-reference table for systematic analysis, state the ion indicated by each observation: (a) a white precipitate with NaOH that dissolves in excess ammonia; (b) a red-brown precipitate with NaOH, insoluble in excess.

Lời giải chi tiết

(a) Zn^{2+} (the precipitate is amphoteric with NaOH, and specifically redissolves in excess ammonia, distinguishing it from Al^{3+}).
(b) Fe^{3+} (red-brown $Fe(OH)_3$, insoluble in excess NaOH).

Bài tập luyện tập

A test tube of gas is held near a naked flame in a fume cupboard as a precaution. The gas bleaches damp litmus paper white. Identify the gas and explain the precaution.

Lời giải chi tiết

The gas is **chlorine**, Cl_2, identified by its bleaching action on damp litmus paper. The fume cupboard precaution is necessary because chlorine is toxic and irritating even at fairly low concentrations, so it should not be inhaled or allowed to accumulate in the open laboratory air.

Bài tập luyện tập

For each of the following, name the most suitable separation technique: (a) recovering pure ethanol from a fermentation mixture of ethanol and water; (b) determining how many dyes make up a sample of ink; (c) separating crude oil into fractions such as petrol and bitumen for industrial use.

Lời giải chi tiết

(a) **Fractional distillation** — ethanol and water are miscible with different boiling points ($78\,^{\circ}$C and $100\,^{\circ}$C).
(b) **Paper chromatography** — the ink is spotted onto paper and run in a solvent; each separate dye appears as its own spot, revealing how many components are present.
(c) **Fractional distillation**, on an industrial scale, in a fractionating tower — hydrocarbons with different chain lengths (and hence different boiling points) condense at different heights in the column.

Bài tập luyện tập

An unknown salt gives a green NaOH precipitate (insoluble in excess) and effervesces with dilute hydrochloric acid, with the gas turning limewater milky. Identify the salt.

Lời giải chi tiết

A green precipitate with NaOH, insoluble in excess, indicates Fe^{2+}. Effervescence with dilute HCl, gas turning limewater milky, indicates CO_3^{2-}. **The salt is iron(II) carbonate,** $FeCO_3$**.**

Ôn tập nhanh toàn bộ chương trình: (1) **Trạng thái vật chất**: rắn/lỏng/khí phân biệt bởi sự sắp xếp và chuyển động hạt; nóng chảy/sôi xảy ra ở nhiệt độ cố định đối với chất tinh khiết. (2) **Nguyên tử, liên kết**: số proton = số hiệu nguyên tử; liên kết ion (kim loại–phi kim, chuyển electron), cộng hoá trị (phi kim–phi kim, dùng chung electron), kim loại (electron tự do, dẫn điện). (3) **Định lượng hoá học**: số mol $=$ khối lượng $\div M_r$; thể tích khí ở r.t.p. $=$ số mol $\times 24$ dm^3; luôn cân bằng phương trình và xác định **chất phản ứng hết trước** (limiting reactant) trước khi tính hiệu suất/độ tinh khiết. (4) **Điện phân**: cation di chuyển về cathode (khử, nhận electron), anion về anode (oxi hoá, mất electron); điện phân nóng chảy tách kim loại hoạt động mạnh, điện phân dung dịch còn cạnh tranh với H_2O. (5) **Năng lượng phản ứng**: toả nhiệt ($\Delta H < 0$) giải phóng năng lượng; thu nhiệt ($\Delta H > 0$) hấp thụ năng lượng; năng lượng liên kết: phá vỡ liên kết thu nhiệt, tạo liên kết mới toả nhiệt. (6) **Tốc độ phản ứng, cân bằng, oxi hoá–khử**: tăng nồng độ/nhiệt độ/diện tích bề mặt/dùng xúc tác đều tăng tốc độ; cân bằng dịch chuyển theo nguyên lý Le Chatelier khi thay đổi điều kiện; OIL RIG — mất electron $=$ oxi hoá, nhận electron $=$ khử. (7) **Axit–bazơ–muối**: axit cho H^+, bazơ/kiềm nhận H^+; phản ứng trung hoà tạo muối $+$ nước; muối điều chế bằng axit $+$ kim loại/oxide bazơ/hydroxide/carbonate. (8) **Bảng tuần hoàn**: tính chất biến đổi tuần hoàn theo nhóm và chu kỳ; nhóm I hoạt động mạnh dần xuống dưới, nhóm VII hoạt động yếu dần xuống dưới; khí hiếm nhóm 0 trơ. (9) **Kim loại**: dãy hoạt động hoá học quyết định phản ứng thế và phương pháp tách (điện phân với kim loại hoạt động mạnh hơn carbon, khử bằng carbon với kim loại kém hoạt động hơn); gỉ sét cần cả nước và oxy. (10) **Hoá học môi trường**: hiệu ứng nhà kính (CO_2, CH_4), mưa axit (SO_2, oxide nitơ), ô nhiễm không khí từ đốt nhiên liệu hoá thạch. (11) **Hoá hữu cơ**: alkane no (liên kết đơn, phản ứng thế), alkene không no (liên kết đôi, phản ứng cộng, làm mất màu nước bromine); rượu, axit carboxylic, ester, polymer (trùng hợp cộng và trùng ngưng). (12) **Phân tích thực nghiệm**: thuộc lòng bảng phép thử khí và ion — đây là phần chắc điểm nhất trong đề Paper 6/thực hành; luôn dùng mẫu mới cho mỗi phép thử và đọc kỹ đơn vị (cm^3 vs dm^3) trước khi tính toán.

Đồng hành cùng 8020 English

Cảm ơn bạn đã học cùng bộ giáo trình quốc tế 8020. **Điểm thật · Thầy thật · Kết quả thật** — nhiều học viên chỉ cần 1–2 khoá để đạt kết quả mong muốn.

Chương trình đào tạo tại 8020 English

IELTS Academic/General · **SAT** · PTE · Duolingo · TOEFL | **AP** (College Board) · **IB** Diploma · **Cambridge** IGCSE / A-Level | săn học bổng du học.

Vì sao chọn 8020 English?

- **100% giáo viên** đạt tối thiểu 8.0 IELTS hoặc 1500 SAT — đội ngũ Giáo sư · Tiến sĩ · Thạc sĩ tốt nghiệp trường top đầu thế giới (Carnegie Mellon — #1 Hoa Kỳ về Khoa học Máy tính).
- **Kèm 1–1** mọi độ tuổi; lớp sĩ số nhỏ 2–5 bạn (đa số dưới 10 bạn/lớp).
- Lộ trình cá nhân hoá, theo sát tiến độ từng học viên; lớp OFFLINE tại TP.HCM & ONLINE toàn quốc.

Bảng vàng học viên

AP 5/5 — Calculus AB/BC	**AP** 4–5 — Biology, Chemistry	**IB** 90/100 — Economics
SAT 1590 / 1570 / 1550	**IELTS** 8.0–9.0	**Duolingo** 110 · **PTE** 90

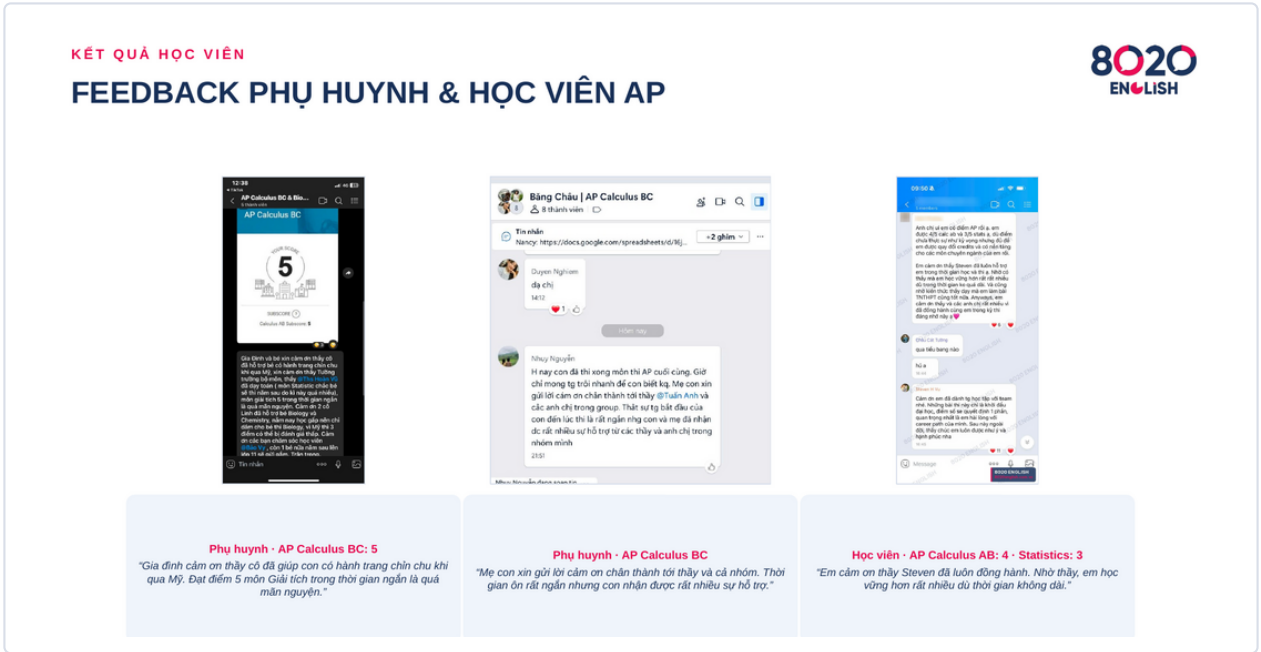
Cảm nhận học viên & phụ huynh

> *"Bạn đã cải thiện được tư duy Writing — kỹ năng từng là nỗi sợ lớn nhất — và cuối cùng đã đậu vào trường top như mong muốn. Thái độ học tập cực kỳ nghiêm túc; ngay cả khi nằm viện vẫn cố gắng học đều đặn."*
>
> — Phan Thị Thanh Hằng · IELTS Overall 8.5

> *"Cần tất cả kỹ năng trên 7.5 để xét vào trường top 1 Anh Quốc về Y học (chương trình UKFPO của NHS) — và đã đạt mục tiêu sau khi học Writing 1–1."*
>
> — Trần Hoàng Bảo Ngọc · IELTS Overall 8.0 (Writing 6.0 → 7.5)

> *"Gia đình và bé xin cảm ơn thầy cô đã giúp con có hành trang chỉn chu khi qua Mỹ. Đạt điểm 5 môn Giải tích trong thời gian ngắn là quá mãn nguyện."*
>
> — Phụ huynh · AP Calculus BC 5/5

> *"Em cảm ơn thầy đã luôn đồng hành. Nhờ thầy, em học vững hơn rất nhiều dù thời gian ôn không dài."*
>
> — Học viên · AP Calculus AB 4

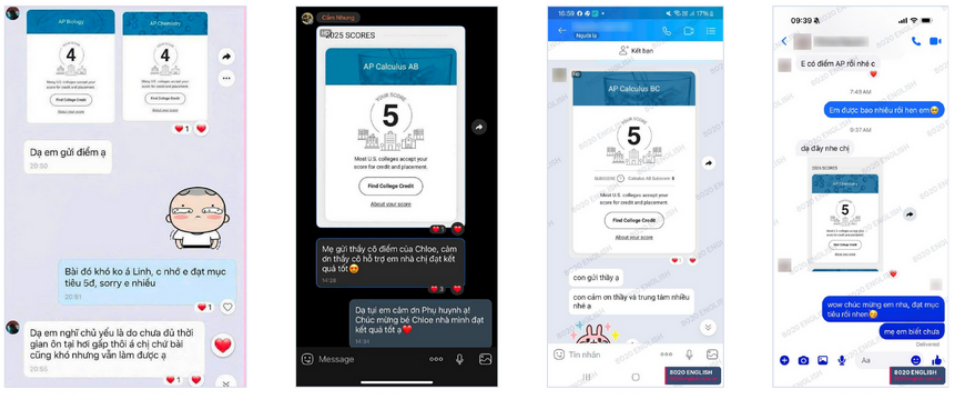


Feedback phụ huynh & học viên AP — nhiều môn đạt điểm 4 & 5

Điểm thi thật của học viên

KẾT QUẢ HỌC VIÊN

ĐIỂM SỐ AP

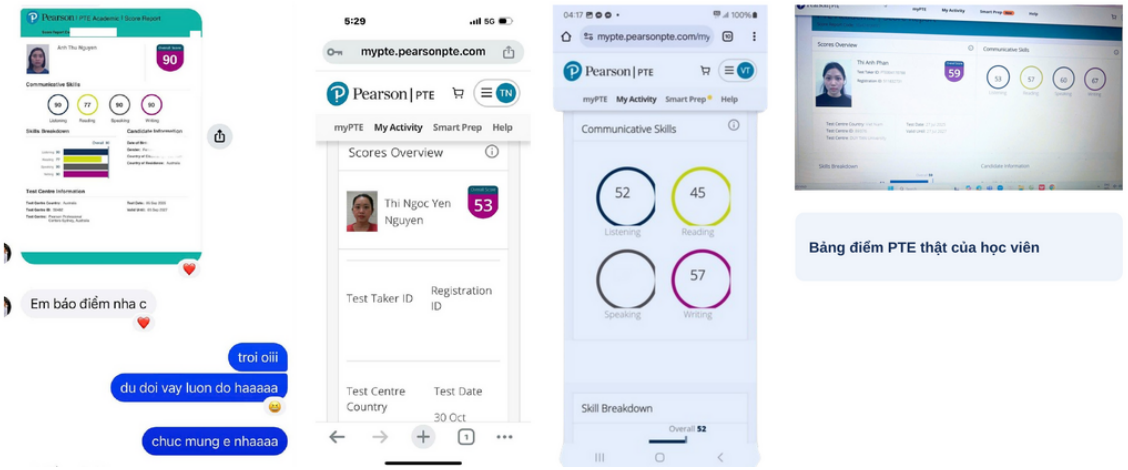


Bảng điểm AP thật của học viên – nhiều môn đạt điểm 4 & 5

Bảng điểm AP thật — Calculus AB/BC 5/5 · Biology & Chemistry 4–5 (College Board)

KẾT QUẢ HỌC VIÊN

ĐIỂM SỐ PTE

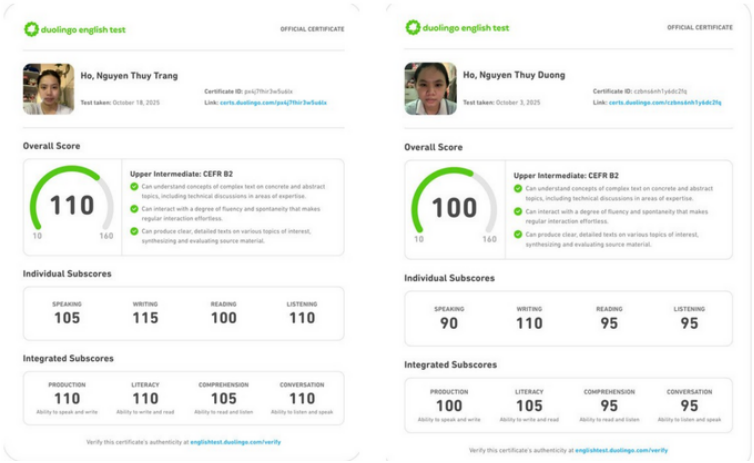


Bảng điểm PTE thật của học viên

Học viên 8020 — PTE Academic 90

KẾT QUẢ HỌC VIÊN

ĐIỂM SỐ DUOLINGO



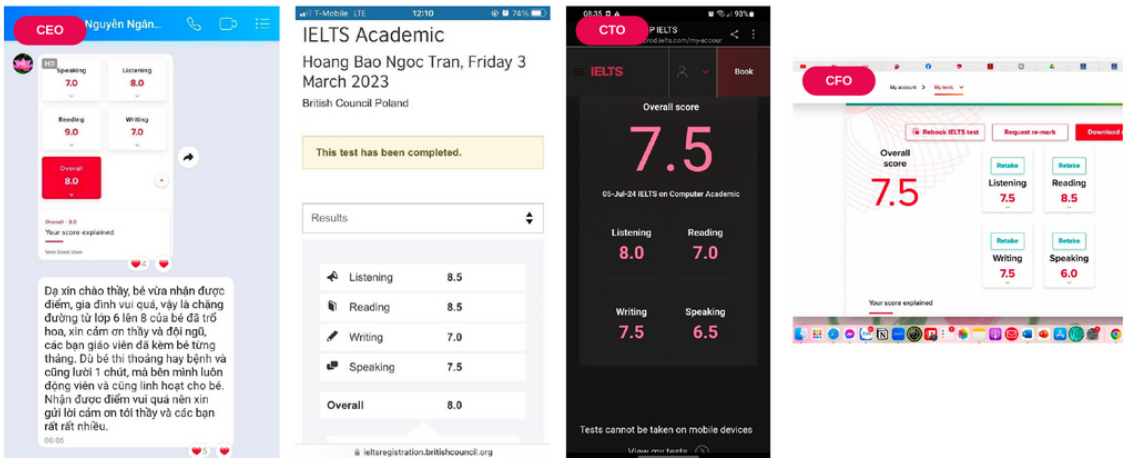
Duolingo English Test – 110 & 100

Học viên 8020 — Duolingo English Test 110 & 100

KẾT QUẢ HỌC VIÊN

THÀNH TÍCH HỌC VIÊN

Bảng điểm thi thật – chất lượng được giám sát nghiêm ngặt. Một số học viên chỉ cần 1–2 khóa để đạt kết quả mong muốn.



Học viên 8020 — IELTS 8.0 / 7.5 / 8.5 (báo điểm thật)