8020 ENGLISH

Cambridge International AS & A Level Biology

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.

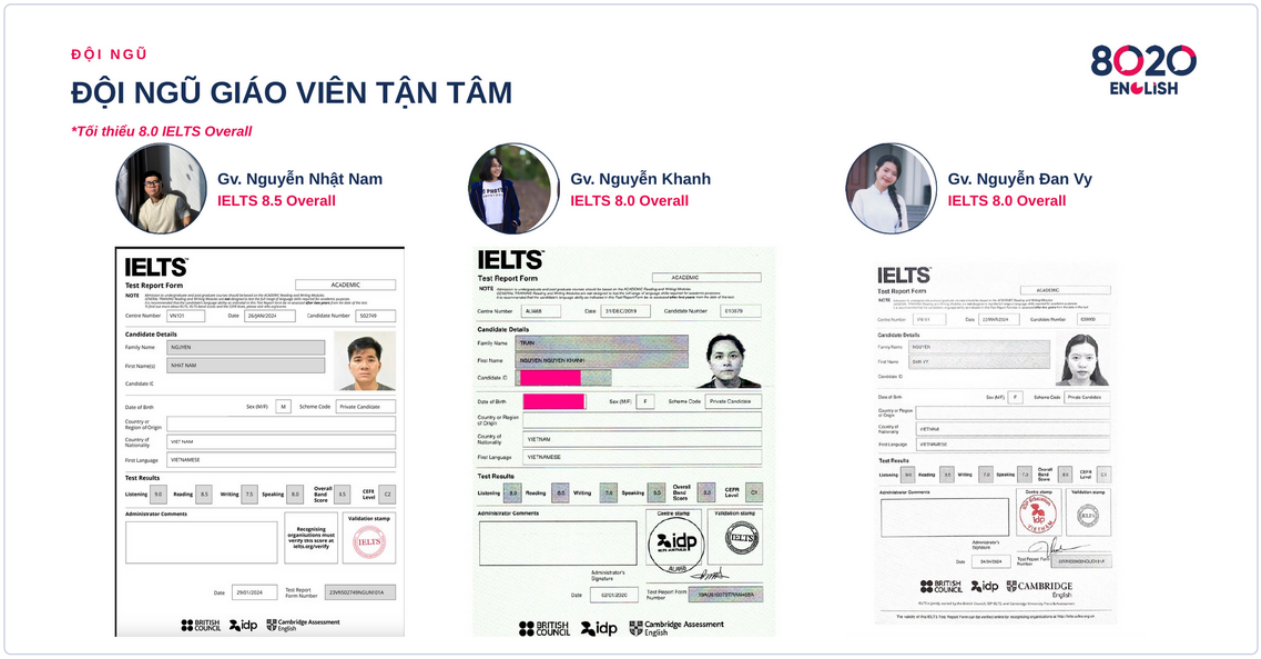
Kết quả học viên — điểm thi thật: IELTS 8.0–9.0 · SAT 1550 / 1570 / 1590 · AP 5/5 (Calculus BC, Microeconomics) · IB 90/100 (Economics) · Duolingo 110 · PTE 90 · TOEFL 120. **Bảng vàng SAT:** Khánh Đăng 1510 · Thảo Nguyên 1520 · Tâm Anh 1530.

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

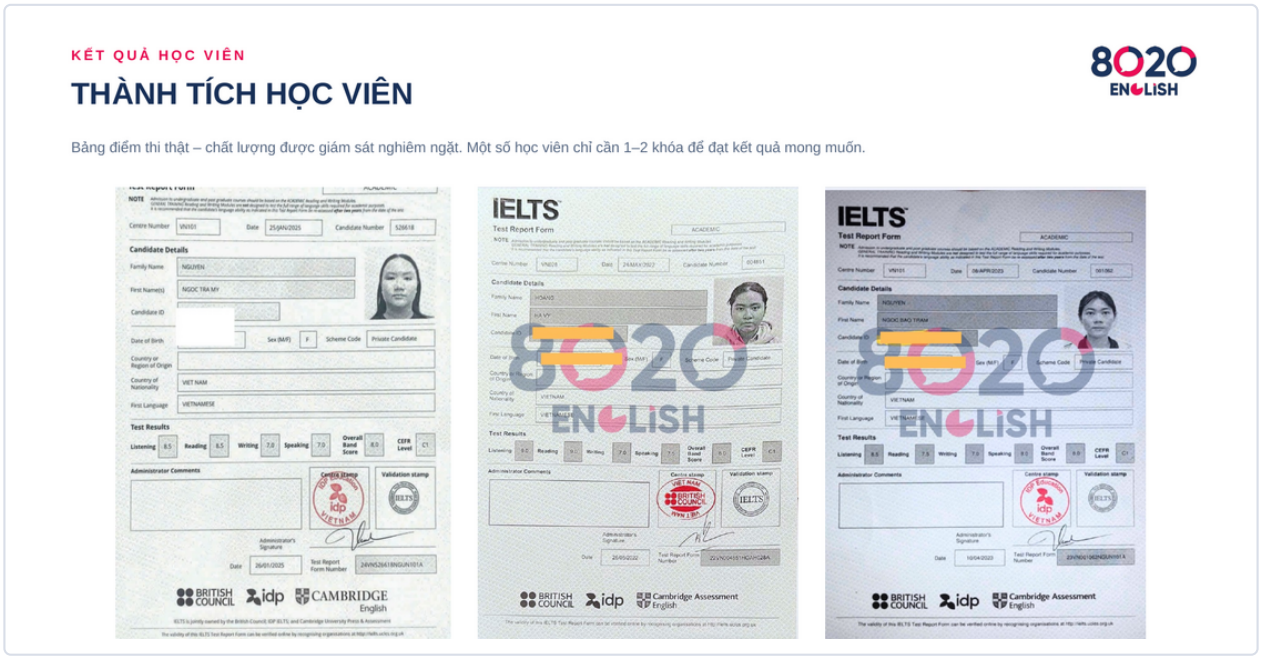
Cách dùng sách hiệu quả: mỗi Unit gồm (1) **Lý thuyết trọng tâm** tiếng Anh kèm **giải thích tiếng Việt**; (2) **Ví dụ mẫu** có lời giải; (3) **Hệ thống bài tập** kèm **lời giải chi tiết**. Hãy tự làm bài trước khi xem lời giải để đạt hiệu quả tối đa.

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)



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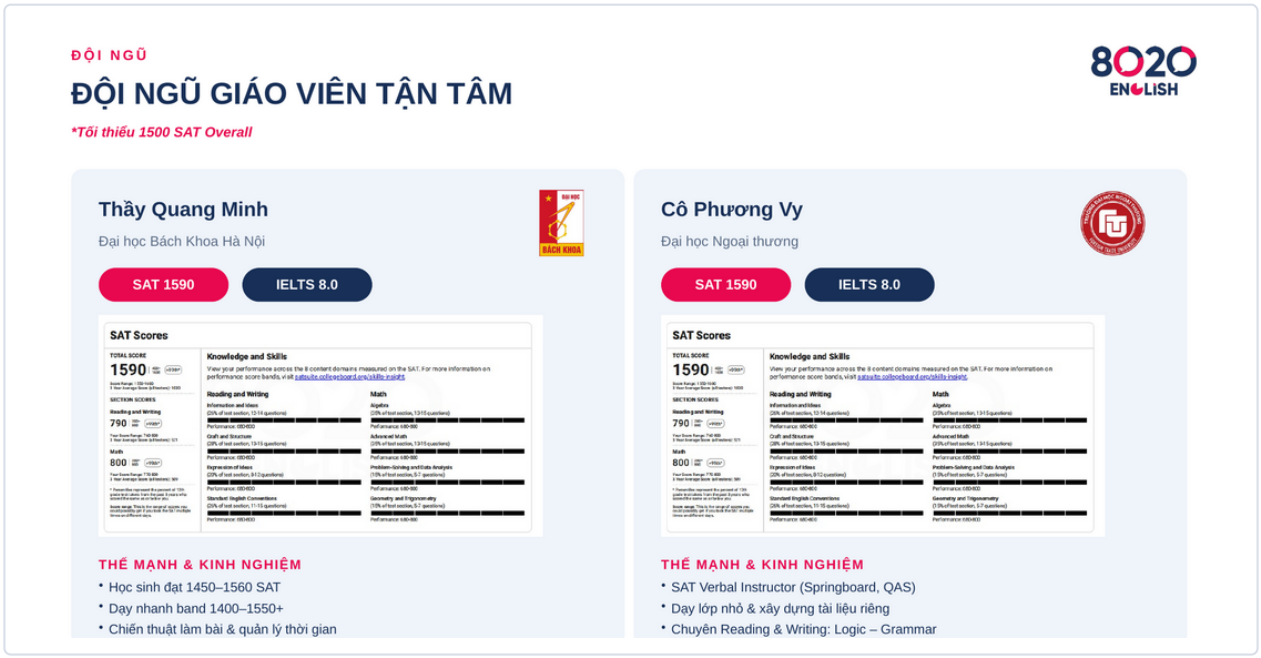
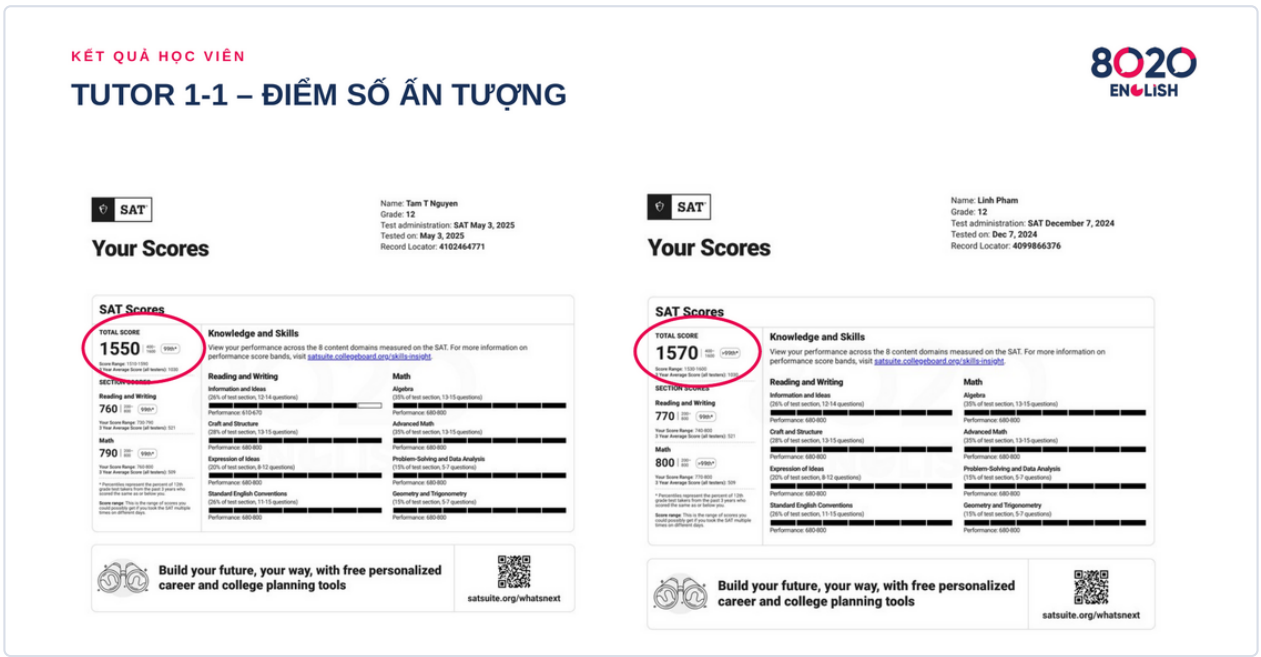
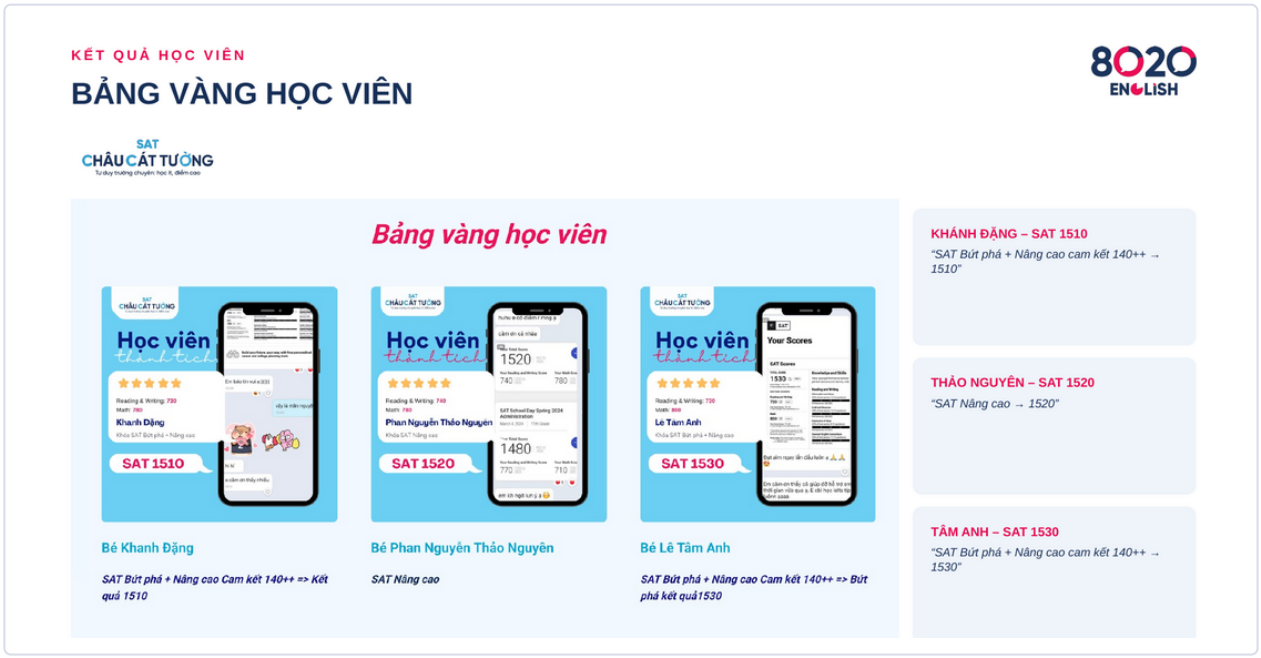


Giảng viên 8020 — SAT 1590 (ĐH Bách Khoa Hà Nội & ĐH Ngoại thương)



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

Cell Structure

AS Level

Mục tiêu Unit: Độ phóng đại và độ phân giải của kính hiển vi quang học, TEM và SEM; công thức tính độ phóng đại $M = \dfrac{\text{kích thước ảnh}}{\text{kích thước thật}}$ và đổi đơn vị mm/μm/nm; siêu cấu trúc chi tiết của tế bào nhân thực (động vật và thực vật); cấu trúc tế bào nhân sơ và bảng so sánh với tế bào nhân thực; cấu trúc virus và lý do virus không được xếp vào giới sinh vật sống; nguyên lý phân tách bào quan bằng đồng hoá mẫu và ly tâm phân đoạn.

1.1 Magnification and Resolution

1.1.1 Defining magnification

Khái niệm cốt lõi

Magnification (M) tells us how many times larger an image is than the real object:

$$M = \frac{\text{image size}}{\text{actual (real) size}}$$

Both sizes must be measured in the *same unit* before dividing. Magnification has no unit — it is written as a multiplying factor, e.g. $\times 400$.

VN **GIẢI THÍCH TIẾNG VIỆT**

Độ phóng đại (M) = kích thước ảnh ÷ kích thước thật. Hai đại lượng này phải được đổi về **cùng một đơn vị** trước khi chia. Độ phóng đại không có đơn vị, chỉ là một con số (ví dụ $\times 400$) cho biết ảnh lớn hơn vật thật bao nhiêu lần.

1.1.2 Defining resolution

Resolution

Resolution (resolving power) is the minimum distance between two points at which they can still be distinguished as two separate points, rather than blurring into one. A microscope with poor resolution can be magnified as much as we like on a screen — the image simply becomes a larger, blurrier version of the same indistinct blob; magnification without resolution reveals no new detail.

(!) Lỗi thường gặp: Học sinh thường nhầm "phóng đại nhiều hơn" với "nhìn rõ hơn". Một kính hiển vi có **độ phân giải kém** thì dù có phóng đại ảnh lên bao nhiêu lần, ta cũng chỉ thấy một vết mờ *to hơn* chứ không thấy thêm chi tiết nào mới. Độ phân giải mới là yếu tố quyết định có thể phân biệt được hai cấu trúc gần nhau hay không — độ phóng đại chỉ đơn thuần làm ảnh to ra.

1.1.3 Units and conversions

Biological structures span a huge range of sizes, so three units are used: the millimetre (mm), the micrometre (μm) and the nanometre (nm).

Unit	Symbol	In metres	Conversion
Millimetre	mm	10^{-3} m	1 mm $= 1000$ μm
Micrometre	μm	10^{-6} m	1 μm $= 1000$ nm
Nanometre	nm	10^{-9} m	1 mm $= 1\,000\,000$ nm

To convert a *larger* unit to a *smaller* one, multiply by 1000 (per step); to convert a *smaller* unit to a *larger* one, divide by 1000.

Ví dụ mẫu · Worked example

Convert 0.0045 mm into μm and into nm.
0.0045 mm $\times\ 1000 = 4.5$ μm. Then 4.5 μm $\times\ 1000 = 4500$ nm. So 0.0045 mm $= 4.5$ μm $= 4500$ nm.

Ví dụ mẫu · Worked example

A ribosome has a diameter of about 25 nm. Express this in μm and in mm.
25 nm $\div\ 1000 = 0.025$ μm. Then 0.025 μm $\div\ 1000 = 0.000025$ mm. So 25 nm $= 0.025$ μm $= 2.5 \times 10^{-5}$ mm.

1.1.4 Why electron microscopes resolve so much more detail

Wavelength and resolving power

Resolving power is fundamentally limited by the **wavelength** of the radiation used to form the image: the shorter the wavelength, the smaller the resolvable distance. Visible light has a wavelength of roughly 400–700 nm, which limits a light microscope's resolution to about 200 nm (0.2 μm). A beam of electrons has a wavelength thousands of times shorter than visible light, so an electron microscope can resolve points as close as about 0.5 nm — around $400\times$ better than a light microscope.

Practical maximum useful magnification: light microscope $\approx\ \times 1500$; electron microscope up to $\times 500\,000$ or more. Magnifying beyond the point where resolution allows new detail to be seen is called **empty magnification** — the image gets bigger but no clearer.

VN **GIẢI THÍCH TIẾNG VIỆT**

Độ phân giải bị giới hạn bởi **bước sóng** của loại bức xạ dùng để tạo ảnh: bước sóng càng ngắn thì độ phân giải càng cao. Ánh sáng nhìn thấy có bước sóng 400–700 nm nên kính hiển vi quang học chỉ phân giải được tới khoảng 200 nm. Chùm electron có bước sóng ngắn hơn ánh sáng hàng nghìn lần, nên kính hiển vi điện tử phân giải được tới khoảng 0.5 nm — tốt hơn khoảng 400 lần. Đây là lý do duy nhất kính hiển vi điện tử nhìn được siêu cấu trúc bên trong bào quan mà kính hiển vi quang học không thể.

1.2 Electron Microscopy: TEM and SEM

1.2.1 Transmission electron microscopy (TEM)

TEM

In a **transmission electron microscope**, a beam of electrons is fired through an extremely thin section of specimen (around 60–100 nm thick). Denser regions of the specimen — often stained with heavy-metal salts such as osmium tetroxide or uranyl acetate to increase electron-scattering contrast — block more electrons, appearing dark on the resulting image; less dense regions let more electrons pass through and appear pale. TEM produces a high-resolution, two-dimensional image of a cell's **internal** ultrastructure.

1.2.2 Scanning electron microscopy (SEM)

SEM

In a **scanning electron microscope**, a fine beam of electrons is scanned back and forth across the **surface** of a specimen (coated in a thin layer of gold or another heavy metal to make it conductive). Electrons bounced or knocked off the surface are collected to build up an image. SEM gives a lower-resolution but strikingly **three-dimensional** image of surface topology.

Both TEM and SEM require the specimen to be **dehydrated and held in a vacuum** (electrons are scattered by air molecules and water vapour), so neither can image living, hydrated cells; specimens must be chemically fixed, and often stained or coated. A light microscope, by contrast, can view living, unstained cells in normal air.

Feature	Light microscope	TEM	SEM
Radiation used	Visible light	Electron beam (transmitted through)	Electron beam (scanned over surface)
Best resolution	≈ 200 nm	≈ 0.5 nm	≈ 20 nm
Max. useful magnification	$\approx \times 1500$	up to $\times 500\,000$	up to $\times 100\,000$
Image type	2-D, coloured possible	2-D, black/white, internal detail	3-D, black/white, surface detail
Living specimens?	Yes	No	No
Sample preparation	Minimal; can stain with dyes	Ultra-thin section, heavy-metal stain, vacuum	Heavy-metal/gold coating, vacuum

VN GIẢI THÍCH TIẾNG VIỆT

TEM (kính hiển vi điện tử truyền qua): electron xuyên *qua* lát cắt siêu mỏng của mẫu, cho ảnh 2 chiều, độ phân giải rất cao, thấy được cấu trúc *bên trong* bào quan. **SEM** (kính hiển vi điện tử quét): electron bật ra từ *bề mặt* mẫu, cho ảnh 3 chiều, độ phân giải thấp hơn TEM nhưng vẫn cao hơn kính hiển vi quang học nhiều. Cả hai đều cần **chân không** và mẫu đã **chết, được xử lý/nhuộm** — không thể quan sát tế bào sống, khác với kính hiển vi quang học.

Ví dụ mẫu · Worked example

An electron micrograph includes a scale bar labelled "$1\ \mu$m", drawn 20 mm long on the printed page. What is the magnification of the micrograph?

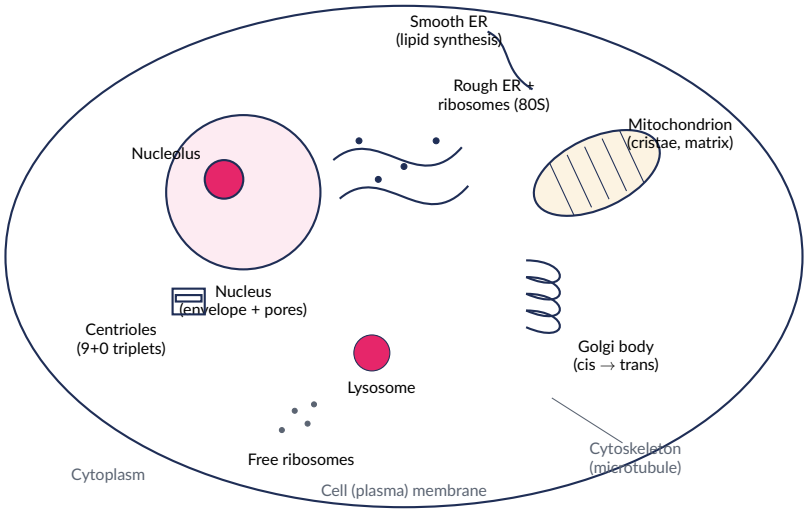
Convert to the same unit: 20 mm $= 20\,000\ \mu$m. This $20\,000\ \mu$m of printed length represents $1\ \mu$m of real structure, so $M = \dfrac{20\,000}{1} = \mathbf{20\,000}\times$.

Ví dụ mẫu · Worked example

A cell biologist wants to find out whether the surface of a white blood cell is smooth or covered in finger-like microvilli. Which microscope technique should be used, and why not the alternatives?

SEM is the correct choice: it images the *outer surface* of a specimen in 3-D, ideal for examining surface texture such as microvilli. TEM would instead show a 2-D slice through the *interior* of the cell (not useful for surface topology), and a light microscope lacks the resolution (only ≈ 200 nm) to distinguish the fine detail of microvilli, which are typically under 100 nm across at the tip.

1.3 Ultrastructure of the Eukaryotic Cell



A generalised animal (eukaryotic) cell: no cell wall, no chloroplasts, no large permanent vacuole.

1.3.1 The nucleus

Khái niệm cốt lõi

The **nucleus** is bounded by a **nuclear envelope** — two membranes with a narrow fluid-filled space between them, continuous at points with the rough ER. The envelope is perforated by **nuclear pores** (large protein-lined channels, ≈ 100 nm across) that allow the controlled passage of large molecules such as messenger RNA and ribosomal subunits between nucleus and cytoplasm. Inside, **chromatin** (DNA wound around histone proteins) is dispersed through the nucleoplasm, and one or more darkly-staining **nucleolus/nucleoli** synthesise ribosomal RNA (rRNA) and assemble ribosomal subunits.

VN **GIẢI THÍCH TIẾNG VIỆT**

Nhân được bao bọc bởi **màng nhân kép** (hai lớp màng), có các **lỗ màng nhân** (nuclear pores) cho phép mRNA và các tiểu đơn vị ribosome đi qua giữa nhân và tế bào chất một cách có kiểm soát. Bên trong nhân là **chất nhiễm sắc** (DNA quấn quanh protein histone) và **hạch nhân (nucleolus)** — nơi tổng hợp rRNA và lắp ráp ribosome.

1.3.2 The endoplasmic reticulum

Khái niệm cốt lõi

The **endoplasmic reticulum (ER)** is a network of membrane-bound sacs and tubules continuous with the nuclear envelope. **Rough ER** has ribosomes studding its outer (cytoplasmic) surface; it folds and processes proteins destined for secretion or for insertion into membranes, then buds off transport vesicles toward the Golgi body. **Smooth ER** lacks ribosomes; it synthesises lipids and steroid hormones, and in some cells (e.g., liver, muscle) detoxifies drugs or stores calcium ions.

VN **GIẢI THÍCH TIẾNG VIỆT**

Lưới nội chất hạt (rough ER) có ribosome bám trên bề mặt, chuyên gấp và xử lý protein để tiết ra ngoài hoặc gắn vào màng. **Lưới nội chất trơn (smooth ER)** không có ribosome, chuyên tổng hợp lipid và hormone steroid.

1.3.3 The Golgi body

Khái niệm cốt lõi

The **Golgi body (apparatus)** is a stack of flattened, membrane-bound sacs (cisternae). Vesicles from the rough ER fuse at the **cis face**; proteins and lipids pass through the stack, are chemically modified (e.g., glycosylated — sugar chains added) and sorted, then bud off as vesicles from the **trans face**, destined for secretion, the cell membrane, or to become lysosomes.

VN **GIẢI THÍCH TIẾNG VIỆT**

Golgi là một chồng túi màng dẹt: mặt **cis** nhận túi vận chuyển từ lưới nội chất hạt; protein/lipid được biến đổi hoá học (ví dụ gắn thêm đường) và phân loại khi đi qua Golgi; cuối cùng nảy chồi thành các túi vận chuyển ở mặt **trans**, đưa đến nơi cần dùng (màng tế bào, tiết ra ngoài, hoặc thành lysosome).

1.3.4 Mitochondria

Khái niệm cốt lõi

Each **mitochondrion** has a double membrane: a smooth outer membrane and a highly folded inner membrane, whose folds are called **cristae**. Cristae greatly increase the surface area available for the membrane-bound enzymes of the electron transport chain and ATP synthase. The fluid interior, the **matrix**, contains the enzymes of the Krebs cycle, plus a small circular loop of DNA and small **70S ribosomes** — features shared with bacteria and consistent with mitochondria having originated as engulfed bacteria (the endosymbiotic theory). Mitochondria are the principal site of aerobic respiration and ATP production.

VN **GIẢI THÍCH TIẾNG VIỆT**

Ti thể có **màng kép**: màng ngoài trơn, màng trong gấp nếp thành **mào (cristae)** để tăng diện tích bề mặt cho chuỗi truyền electron và enzyme ATP synthase hoạt động. **Chất nền (matrix)** chứa enzyme chu trình Krebs, cùng với DNA vòng riêng và ribosome $70S$ — giống vi khuẩn, ủng hộ **thuyết nội cộng sinh (endosymbiotic theory)** cho rằng ti thể có nguồn gốc từ vi khuẩn bị một tế bào lớn hơn nuốt vào.

1.3.5 Lysosomes

Khái niệm cốt lõi

A **lysosome** is a single membrane-bound sac, budded from the Golgi body, packed with **hydrolytic (digestive) enzymes** that work best at an acidic pH (≈ 5) maintained inside the lysosome. Lysosomes break down worn-out organelles (autophagy), digest material taken in by phagocytosis (e.g., a white blood cell destroying a bacterium), and can trigger the controlled breakdown of the whole cell (apoptosis).

VN **GIẢI THÍCH TIẾNG VIỆT**

Lysosome là túi màng đơn chứa **enzyme thuỷ phân** hoạt động tối ưu ở pH acid (≈ 5). Chức năng: phân huỷ bào quan già cỗi (tự thực bào), tiêu hoá vật chất do thực bào đưa vào (ví dụ bạch cầu tiêu diệt vi khuẩn), và có thể kích hoạt quá trình chết theo chương trình của tế bào (apoptosis).

1.3.6 Ribosomes

Khái niệm cốt lõi

Ribosomes are small structures (not membrane-bound) built of rRNA and protein, made of a large and a small subunit. Eukaryotic cytoplasmic ribosomes are the larger **80S** type; **free ribosomes**, scattered in the cytoplasm, make proteins used within the cell itself, while **bound ribosomes**, attached to rough ER, make proteins for secretion, for lysosomes, or for insertion into membranes.

VN **GIẢI THÍCH TIẾNG VIỆT**

Ribosome gồm 2 tiểu đơn vị (rRNA $+$ protein), không có màng bao bọc. **Ribosome tự do** nằm rải rác trong tế bào chất, tổng hợp protein dùng ngay trong tế bào. **Ribosome gắn** trên lưới nội chất hạt tổng hợp protein để tiết ra ngoài hoặc gắn vào màng.

1.3.7 The cytoskeleton

Cytoskeleton

The **cytoskeleton** is an internal network of protein fibres running through the cytoplasm, giving mechanical support and enabling movement.

- **Microtubules** — hollow tubes of the protein tubulin (≈ 25 nm diameter); form tracks along which motor proteins (kinesin, dynein) drag vesicles and organelles; form the mitotic spindle; form the core of cilia and flagella.
- **Microfilaments** — thin solid strands of the protein actin (≈ 7 nm diameter); involved in cell shape, cell movement (e.g. crawling, cytoplasmic streaming) and pinching the cell in two

during cytokinesis.

- **Intermediate filaments** — rope-like fibres (≈ 10 nm diameter) that resist mechanical stress, anchoring the nucleus and other organelles in place.

VN **GIẢI THÍCH TIẾNG VIỆT**

Bộ khung xương tế bào (cytoskeleton) gồm 3 loại sợi: **vi ống (microtubule)** — ống rỗng bằng tubulin, làm đường ray vận chuyển bào quan và tạo thoi phân bào; **vi sợi (microfilament)** — sợi actin đặc, tham gia thay đổi hình dạng, di chuyển tế bào và phân chia tế bào chất; **sợi trung gian (intermediate filament)** — bền cơ học, neo giữ nhân và bào quan tại chỗ.

1.3.8 Centrioles and the mitotic spindle

Khái niệm cốt lõi

Centrioles are small cylindrical structures made of nine triplets of microtubules arranged in a ring (a "$9 + 0$" arrangement); a pair of centrioles at right angles forms a **centrosome**. In animal cells, the centrosome organises the **mitotic spindle** — the microtubule fibres that attach to chromosomes and pull sister chromatids apart during cell division. Most flowering plant cells lack centrioles altogether, yet still form a functional spindle, showing that centrioles are not strictly essential for spindle formation.

VN **GIẢI THÍCH TIẾNG VIỆT**

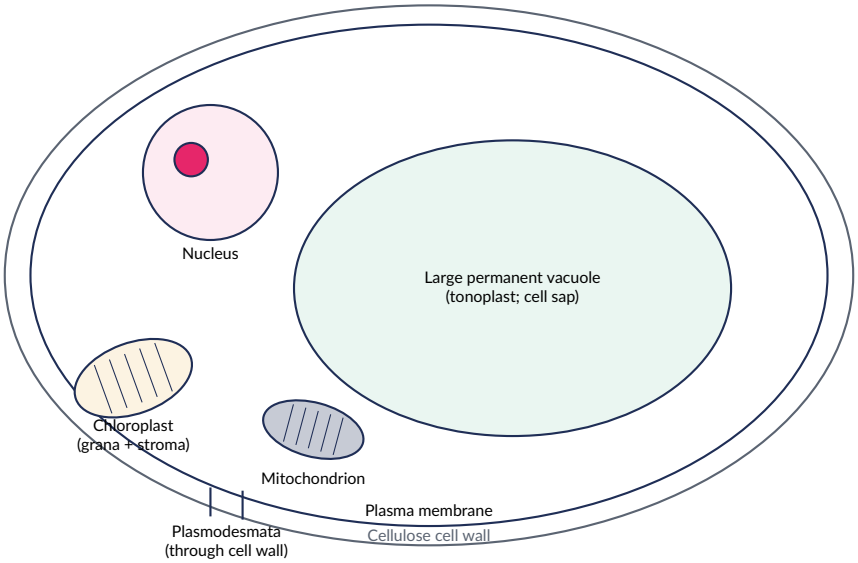
Trung thể (centriole) gồm 9 bộ ba vi ống xếp thành vòng, một cặp trung thể tạo thành centrosome — nơi tổ chức **thoi phân bào (mitotic spindle)** kéo nhiễm sắc tử về hai cực tế bào khi phân chia. Đa số tế bào thực vật có hoa không có trung thể nhưng vẫn tạo được thoi phân bào bình thường.

1.3.9 The cell surface membrane

The **cell surface membrane** is a phospholipid bilayer studded with proteins that forms the outer boundary of the cell, controlling the movement of substances into and out of the cell (its detailed structure and transport functions are covered in the membranes unit).

Nucleus	Double envelope with pores; chromatin (DNA + histone); nucleolus makes rRNA/ribosomes.
Rough ER	Ribosome-studded membrane sheets; folds/transports secretory and membrane proteins.
Smooth ER	No ribosomes; synthesises lipids and steroids.
Golgi body	Modifies, sorts and packages proteins/lipids into vesicles (cis → trans).
Mitochondrion	Double membrane, cristae, matrix; own DNA & 70S ribosomes; aerobic respiration.
Lysosome	Single-membrane sac of hydrolytic enzymes at acidic pH.
Ribosome	80S (eukaryotic cytoplasm); free = for cytoplasmic use, bound = for secretion.
Cytoskeleton	Microtubules, microfilaments, intermediate filaments — shape, transport, division.
Centrioles	9 microtubule triplets; organise the mitotic spindle in animal cells.

1.4 Plant Cell Structures



A generalised plant cell: note the cellulose wall (outside the membrane), the large central vacuole, chloroplasts and plasmodesmata — all absent from animal cells.

1.4.1 The cellulose cell wall

Khái niệm cốt lõi

Plant cells are surrounded by a rigid **cell wall** of **cellulose** microfibrils embedded in a matrix of other polysaccharides, lying outside the cell surface membrane. It is **freely permeable** to water and solutes (unlike the membrane), and provides mechanical strength that prevents the cell from bursting when water enters by osmosis, allowing internal **turgor pressure** to build up and support the plant. Adjacent cell walls are cemented together by a pectin-rich layer, the **middle lamella**.

VN **GIẢI THÍCH TIẾNG VIỆT**

Thành tế bào thực vật làm từ vi sợi **cellulose**, nằm ngoài màng sinh chất, **thấm tự do** với nước và chất tan (khác với màng tế bào có chọn lọc). Nhờ có thành tế bào, tế bào không bị vỡ khi nước đi vào bằng thẩm thấu, mà tạo ra **áp suất trương (turgor pressure)** giúp cây đứng vững. Các thành tế bào liền kề được gắn kết với nhau bởi **lớp giữa (middle lamella)** giàu pectin.

1.4.2 The vacuole

Khái niệm cốt lõi

Mature plant cells typically have one **large permanent (central) vacuole**, bound by a single membrane called the **tonoplast**. It is filled with **cell sap** — a solution of sugars, ions, organic acids, pigments and waste products — which lowers the water potential of the cell, drawing water in by osmosis and generating turgor pressure against the cell wall.

VN **GIẢI THÍCH TIẾNG VIỆT**

Không bào lớn cố định được bao bọc bởi màng **tonoplast**, chứa **dịch tế bào (cell sap)** gồm đường, ion, acid hữu cơ, sắc tố. Dịch tế bào làm giảm thế nước của tế bào, kéo nước vào bằng thẩm thấu, tạo áp suất trương ép vào thành tế bào.

1.4.3 Chloroplasts

Khái niệm cốt lõi

A **chloroplast** has a double envelope membrane surrounding a fluid **stroma**, which contains the enzymes of the Calvin cycle, starch grains, and — like the mitochondrion — its own small circular DNA and **70S ribosomes**. Suspended in the stroma are stacks of flattened membrane sacs called **thylakoids**; a stack of thylakoids is a **granum** (plural: grana), and grana are linked by connecting membranes (lamellae). Chlorophyll and other photosynthetic pigments are embedded in the thylakoid membranes, making chloroplasts the site of photosynthesis.

VN **GIẢI THÍCH TIẾNG VIỆT**

Lục lạp có **màng kép**, bên trong là **chất nền (stroma)** chứa enzyme chu trình Calvin, hạt tinh bột, và DNA/ribosome 70S riêng (giống ti thể, cũng ủng hộ thuyết nội cộng sinh). Bên trong stroma là các túi màng dẹt **thylakoid** xếp chồng thành **grana**, nối với nhau bằng các màng liên kết (lamellae). Diệp lục và sắc tố quang hợp nằm trên màng thylakoid — đây là nơi diễn ra quang hợp.

1.4.4 Plasmodesmata

Khái niệm cốt lõi

Plasmodesmata (singular: plasmodesma) are narrow channels through the cell wall that connect the cytoplasm of adjacent plant cells, lined by continuous cell surface membrane and often containing a thin strand of ER. They allow water, ions and small molecules to move directly between cells (the **symplast pathway**) without crossing an additional membrane at every cell boundary.

VN **GIẢI THÍCH TIẾNG VIỆT**

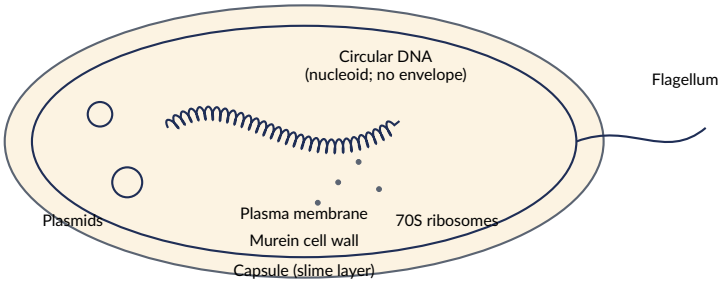
Plasmodesmata là các kênh nhỏ xuyên qua thành tế bào, nối liền tế bào chất của các tế bào thực vật liền kề, cho phép nước và chất tan di chuyển trực tiếp giữa các tế bào theo **con đường symplast** mà không cần đi qua thêm màng tế bào ở mỗi ranh giới.

Ví dụ mẫu · Worked example

List three structures found in a plant cell but never in an animal cell, and state the function of each.

Cellulose cell wall — freely permeable, provides mechanical support and generates turgor pressure. **Large permanent (central) vacuole** — bound by the tonoplast, stores cell sap and maintains turgor. **Chloroplast** — double membrane, thylakoids/grana + stroma, site of photosynthesis. (Plasmodesmata are also plant-specific, connecting cytoplasm between cells.)

1.5 Prokaryotic Cells



A generalised prokaryotic (bacterial) cell: no nucleus and no membrane-bound organelles.

1.5.1 Prokaryotic cell structure

Khái niệm cốt lõi

Prokaryotic (bacterial) cells lack a true, membrane-bound nucleus and lack membrane-bound organelles altogether. Their genetic material is a single **circular DNA molecule**, not associated with histone proteins, lying free in the cytoplasm in a region called the **nucleoid** (not enclosed by any envelope). Many bacteria also carry one or more small circles of DNA called **plasmids**, which often carry genes such as antibiotic resistance and can be exchanged between bacteria. Ribosomes are the smaller **70S** type. The cell wall is built of **murein (peptidoglycan)**, chemically quite different from a plant's cellulose wall, and is often surrounded by a protective, adhesive **capsule (slime layer)**. Many bacteria swim using a **flagellum**, a much simpler rotating structure than the eukaryotic flagellum. Prokaryotic cells are typically far smaller (1–5 μm) than eukaryotic cells (10–100 μm).

(!) Lỗi thường gặp: "Nhân sơ không có nhân" không có nghĩa là không có DNA — vi khuẩn vẫn có DNA (dạng vòng, tự do trong tế bào chất, không có màng bao bọc). Đừng nhầm ribosome 70S (vi khuẩn, và cả ti thể/lục lạp) với 80S (tế bào chất tế bào nhân thực) — đây là cơ sở để một số kháng sinh (ví dụ streptomycin) chỉ tấn công ribosome 70S của vi khuẩn mà không ảnh hưởng ribosome 80S của người.

1.5.2 Comparing prokaryotic and eukaryotic cells

Feature	Prokaryotic cell	Eukaryotic cell
Nucleus	Absent — circular DNA free in cytoplasm (nucleoid)	Present — DNA enclosed by nuclear envelope
DNA form	Circular, no histones; plasmids may be present	Linear, wound around histone proteins
Ribosomes	70S (smaller)	80S (larger); 70S inside mitochondria/chloroplasts
Membrane-bound organelles	None (no mitochondria, ER, Golgi)	Present (mitochondria, ER, Golgi, etc.)
Cell wall	Murein (peptidoglycan)	Cellulose (plants), chitin (fungi), or absent (animals)
Typical size	1–5 μm	10–100 μm
Cell division	Binary fission	Mitosis / meiosis

VN **GIẢI THÍCH TIẾNG VIỆT**

Bảng so sánh cho thấy khác biệt cốt lõi: tế bào nhân sơ **không có màng nhân** và **không có bào quan có màng bao bọc**, DNA dạng vòng tự do, ribosome 70S nhỏ hơn; tế bào nhân thực có nhân thật (màng bao bọc), nhiều bào quan có màng, ribosome 80S lớn hơn, và kích thước lớn hơn nhiều (thường gấp 10–20 lần).

1.6 Viruses

1.6.1 Structure of a virus

Khái niệm cốt lõi

A **virus** is not a cell: it has no cytoplasm, no ribosomes and no metabolic machinery of its own, and cannot reproduce without hijacking a host cell's machinery (an **obligate intracellular parasite**). Every virus has a protein coat, the **capsid** (built of repeating protein subunits called capsomeres), enclosing a core of nucleic acid — either DNA or RNA, single- or double-stranded, depending on the virus. Some viruses additionally have a lipid **envelope**, derived from the host cell's own membrane as the virus buds out, studded with virus-encoded **attachment proteins** that recognise and bind specific receptor molecules on a host cell's surface. Viruses are extremely small — typically 20–300 nm — smaller than the smallest bacteria, and can only be resolved using an electron microscope.

HIV (human immunodeficiency virus) illustrates this structure: a cone-shaped capsid encloses two copies of single-stranded RNA plus the enzyme reverse transcriptase; a lipid envelope (from the host cell membrane) surrounds the capsid, studded with attachment glycoproteins (gp120/gp41) that bind CD4 receptors on host helper T lymphocytes.

VN **GIẢI THÍCH TIẾNG VIỆT**

Virus **không phải tế bào**: không có tế bào chất, không có ribosome, không tự trao đổi chất, chỉ nhân lên được nhờ chiếm dụng bộ máy của tế bào chủ. Mọi virus đều có **capsid** (vỏ protein) bao quanh **lõi acid nucleic** (DNA hoặc RNA); một số virus có thêm **màng bao (envelope)** lấy từ màng tế bào chủ, gắn **protein bám dính** để nhận diện thụ thể trên tế bào chủ. HIV là ví dụ: capsid hình nón chứa RNA và enzyme phiên mã ngược, có màng bao với glycoprotein gp120/gp41 gắn vào thụ thể CD4 của tế bào lympho T hỗ trợ.

1.6.2 Why viruses are not classified as living

Khái niệm cốt lõi

Viruses are excluded from the classification of living organisms because they lack the defining features of a cell: no cytoplasm or organelles, no independent metabolism (no respiration, no protein synthesis machinery of their own), and no capacity to reproduce by themselves — they can only replicate by hijacking a host cell's ribosomes, enzymes and energy supply to copy their genetic material and manufacture new capsid proteins.

VN **GIẢI THÍCH TIẾNG VIỆT**

Virus không được xếp vào sinh vật sống vì thiếu các đặc điểm cốt lõi của tế bào: không có tế bào chất/bào quan, không tự trao đổi chất độc lập, và không thể tự nhân lên — chỉ có thể nhân lên bằng cách chiếm dụng ribosome, enzyme và năng lượng của tế bào chủ.

1.7 Cell Fractionation and Ultracentrifugation

1.7.1 Homogenisation

Khái niệm cốt lõi

Cell fractionation separates the different organelles of a cell so that each type can be studied (or its function tested) in isolation. The tissue sample is first ground up in a blender in an ice-cold, isotonic, buffered solution — a process called **homogenisation**:

- **Ice-cold** — reduces the activity of enzymes (including hydrolytic enzymes released from broken lysosomes), preventing the organelles being digested or damaged after the cell is broken open.
- **Isotonic** (same water potential as the cytoplasm) — prevents water moving into or out of the organelles by osmosis, which would otherwise make them swell and burst, or shrink and shrivel.
- **Buffered** (constant pH) — prevents pH changes that would denature enzymes and other proteins in the released organelles.

The resulting homogenate is then **filtered** through gauze to remove any unbroken cells, large cell debris and connective tissue.

VN **GIẢI THÍCH TIẾNG VIỆT**

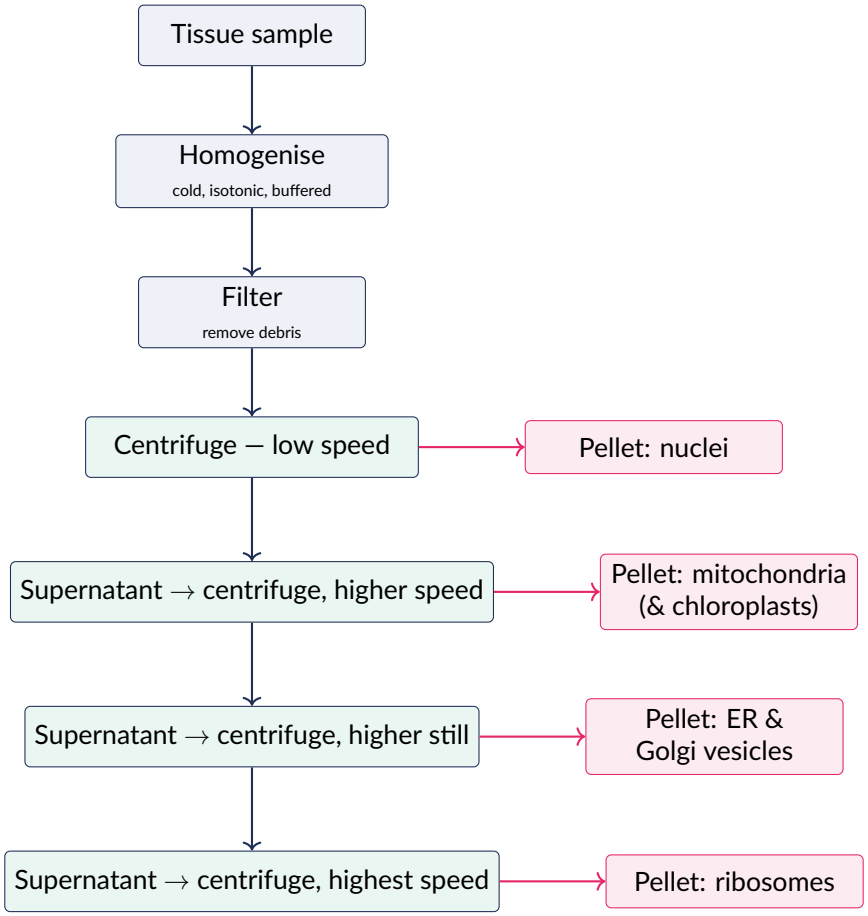
Đồng hoá mẫu (homogenisation) phải thực hiện trong dung dịch **lạnh** (giảm hoạt tính enzyme, tránh bào quan bị enzyme thuỷ phân từ lysosome vỡ ra phân huỷ), **đẳng trương** (tránh nước di chuyển vào/ra bào quan bằng thẩm thấu làm bào quan phồng vỡ hoặc teo lại), và **có đệm pH** (tránh biến tính enzyme/protein do thay đổi pH). Sau đó dịch được **lọc** qua vải mỏng để loại tế bào chưa vỡ và mảnh vụn lớn.

1.7.2 Differential centrifugation

Khái niệm cốt lõi

The filtered homogenate is spun in an **ultracentrifuge** at successively higher speeds — **differential centrifugation**. At each speed, the largest/densest structures still in suspension are forced to the bottom of the tube, forming a **pellet**; the remaining fluid (**supernatant**) containing smaller/lighter structures is poured off and spun again at a higher speed. Organelles are collected, largest and densest first:

1. Low speed, short time: **nuclei** (largest, densest) pellet first.
2. Medium speed: **mitochondria and chloroplasts** pellet.
3. Higher speed, longer time: **endoplasmic reticulum fragments, Golgi vesicles and lysosomes** pellet.
4. Highest speed, longest time: **ribosomes** (smallest, least dense) pellet last.



Cell fractionation by differential centrifugation: increasing speed at each stage pellets progressively smaller, less dense organelles.

VN **GIẢI THÍCH TIẾNG VIỆT**

Ly tâm phân đoạn (differential centrifugation): quay ở tốc độ thấp trước tiên để lắng bào quan **to và đặc nhất** (nhân), sau đó tăng dần tốc độ để lần lượt lắng ti thể/lục lạp, rồi mảnh lưới nội chất/Golgi, và cuối cùng là ribosome (nhỏ và nhẹ nhất). Thứ tự lắng phụ thuộc vào **kích thước và mật độ** của từng bào quan.

Ví dụ mẫu · Worked example

A student homogenises liver tissue and centrifuges the filtrate at increasing speeds. Explain why nuclei sediment out before mitochondria, and why mitochondria sediment out before ribosomes.

Under a centrifugal force, the rate at which a structure sediments depends on its **size and density**: larger, denser structures experience a greater sedimenting force at a given speed and settle out first. Nuclei are the largest and densest structures in the homogenate, so they pellet at the lowest speed. Mitochondria are smaller and less dense than nuclei but larger/denser than ribosomes, so they require a higher speed to sediment; ribosomes, being the smallest and least dense structures, only pellet at the highest speeds used.

Ví dụ mẫu · Worked example

Explain why the homogenising solution must be (a) ice-cold, (b) isotonic and (c) buffered. (3 marks — one reason per condition.)

(a) Ice-cold: slows down enzyme activity (including hydrolytic enzymes released from any lysosomes broken during homogenisation), reducing damage to/breakdown of the organelles being isolated. **(b) Isotonic:** matches the water potential inside the organelles, so no net osmotic movement of water occurs — organelles do not swell and burst (hypotonic solution) or shrink and shrivel (hypertonic solution). **(c) Buffered:** keeps pH constant, preventing denaturation of the enzymes and other proteins within the organelles being studied.

1.8 Calculating Actual Size and Magnification

This is one of the most frequently tested numerical skills in this unit: rearranging $M = \dfrac{\text{image size}}{\text{actual size}}$ to find whichever quantity is unknown, always after converting to consistent units.

$$M = \frac{I}{A} \qquad \Rightarrow \qquad A = \frac{I}{M} \qquad \Rightarrow \qquad I = A \times M$$

where I = image size, A = actual size, M = magnification. Always convert I and A to the *same* unit before applying the formula.

Ví dụ mẫu · Worked example

A mitochondrion appears 45 mm long in an electron micrograph. Its actual length is 3 μm. Calculate the magnification.

Convert to the same unit: 45 mm $= 45\,000$ μm. $M = \dfrac{45\,000}{3} =$ **15 000**$\times$.

Ví dụ mẫu · Worked example

A student draws a chloroplast 60 mm long at a stated magnification of $\times 6000$. Calculate its actual length, in μm.

Rearranging: $A = \dfrac{I}{M} = \dfrac{60 \text{ mm}}{6000} = 0.01$ mm $=$ **10** μm — consistent with a real chloroplast (3–10 μm).

Ví dụ mẫu · Worked example

An electron micrograph shows a nuclear pore with a measured diameter of 15 mm at a magnification of $\times 150\,000$. Calculate the actual diameter of the nuclear pore, in nm, and comment on whether this is a realistic value.

$A = \dfrac{I}{M} = \dfrac{15 \text{ mm}}{150\,000} = 0.0001$ mm $= 0.1$ μm $= 100$ nm. This matches the accepted real diameter of a nuclear pore (≈ 100 nm), so the value is realistic.

1.9 Practice Questions

Bài tập luyện tập

An organelle appears 18 mm wide in a photomicrograph. Its actual width is $2\ \mu$m. What is the magnification?

(A) $9\times$
(B) $900\times$
(C) $9\,000\times$
(D) $90\,000\times$

Lời giải chi tiết

Convert: 18 mm $= 18\,000\ \mu$m. $M = \dfrac{18\,000}{2} = 9\,000\times$. **(C)**.

Bài tập luyện tập

Which feature is present in a bacterial cell but *absent* from a plant cell?

(A) A cell wall
(B) Ribosomes
(C) A single circular DNA molecule free in the cytoplasm, plus plasmids
(D) A cell membrane

Lời giải chi tiết

Both cell types have walls, ribosomes and membranes — but only bacteria have DNA as a free circular chromosome (no nuclear envelope) plus separate plasmids; plant cells have a true, membrane-bound nucleus. **(C)**.

Bài tập luyện tập

A researcher wants to see the internal arrangement of cristae inside a mitochondrion. Which technique is required, and why?

(A) Light microscopy, because it can view living, unstained cells
(B) TEM, because its very high resolution can distinguish internal structures only a few nm apart
(C) SEM, because it gives a 3-D external view
(D) The naked eye, because mitochondria are large enough to see directly

Lời giải chi tiết

Cristae are internal membrane folds only tens of nanometres apart — far below the 200 nm resolution limit of light microscopy. Only the electron microscope (TEM images internal ultrastructure of thin sections) has sufficient resolution. **(B)**.

Bài tập luyện tập

Which statement about ribosome size is correct?

(A) Both eukaryotic and bacterial ribosomes are 80S

(B) Eukaryotic ribosomes are 70S; bacterial ribosomes are 80S

(C) Eukaryotic (cytoplasmic) ribosomes are 80S; bacterial ribosomes are the smaller 70S

(D) Ribosome size cannot be compared between species

Lời giải chi tiết

Eukaryotic cytoplasmic ribosomes are the larger 80S type; bacterial ribosomes (and those inside mitochondria/chloroplasts) are the smaller 70S type — exploited by antibiotics that target only 70S ribosomes. **(C)**.

Bài tập luyện tập

An electron micrograph is labelled with a stated magnification of $\times 13\,000$; a mitochondrion measured in the image is 52 mm wide. However, a scale bar printed on the micrograph is 25 mm long and labelled "500 nm". (a) Calculate the true magnification indicated by the scale bar. (b) Use this true magnification to calculate the actual width of the mitochondrion, in nm. (c) Explain why the stated magnification cannot be trusted.

Lời giải chi tiết

(a) Convert the scale bar to the same unit: 25 mm $= 25\,000\,000$ nm represents 500 nm of real structure. True $M = \dfrac{25\,000\,000}{500} =$ **50 000**$\times$. **(b)** Actual width $= \dfrac{I}{M} = \dfrac{52\text{ mm}}{50\,000} = 0.00104$ mm $=$ $1.04\ \mu$m $=$ **1040** nm (a realistic mitochondrial diameter). **(c)** The stated magnification ($\times 13\,000$) would give a very different (and unrealistically large) actual width of 52 mm $\div\ 13\,000 \approx 4\ \mu$m-width for a cross-section — printing/reproduction of an image (e.g. resizing for a textbook) commonly changes its true magnification, so the scale bar (measured directly on the printed image) is always the more reliable reference than a stated figure.

Bài tập luyện tập

Which of the following correctly pairs an organelle with its function?

(A) Golgi body — synthesises lipids and steroid hormones

(B) Smooth ER — modifies and packages proteins into vesicles

(C) Rough ER — folds and processes proteins made by attached ribosomes for secretion

(D) Lysosome — synthesises ATP by aerobic respiration

Lời giải chi tiết

Rough ER, studded with ribosomes, folds/processes proteins bound for secretion or membrane insertion. (Smooth ER, not Golgi, makes lipids/steroids; Golgi, not smooth ER, modifies/packages; mitochondria, not lysosomes, make ATP.) **(C)**.

Bài tập luyện tập

Explain, in terms of surface area, why the inner membrane of a mitochondrion is folded into cristae.

Lời giải chi tiết

Folding the inner membrane into cristae greatly increases its **surface area** within the same overall organelle volume. Since the electron transport chain proteins and ATP synthase enzymes are embedded in this membrane, a larger membrane surface area allows many more of these proteins to be packed in, increasing the rate at which ATP can be produced by aerobic respiration.

Bài tập luyện tập

A cell biologist counts free ribosomes and bound ribosomes in a pancreas cell (which secretes digestive enzymes) and compares it with a skin cell (which makes little secreted protein). Predict which cell type has proportionally more *bound* ribosomes, and explain why.

Lời giải chi tiết

The **pancreas cell** would have proportionally more bound ribosomes (attached to rough ER). Bound ribosomes synthesise proteins destined for secretion out of the cell; since the pancreas cell's main role is to secrete large quantities of digestive enzymes, it needs extensive rough ER and many bound ribosomes to meet this demand, whereas the skin cell, making comparatively little secreted protein, relies more on free ribosomes for proteins used within its own cytoplasm.

Bài tập luyện tập

Which structure is responsible for organising the mitotic spindle in an animal cell, and what is its internal arrangement of microtubules?

(A) The nucleolus; a ring of nine microtubule doublets

(B) The centriole; nine triplets of microtubules arranged in a ring

(C) The Golgi body; six pairs of microtubules

(D) The lysosome; a single central microtubule

Lời giải chi tiết

A pair of centrioles, each built of nine microtubule triplets arranged in a ring, forms the centrosome that organises the mitotic spindle in animal cells. **(B)**.

Bài tập luyện tập

State and explain one structural difference between a microtubule and a microfilament that relates to their different roles.

Lời giải chi tiết

Microtubules are hollow tubes of tubulin protein, about 25 nm in diameter — this larger, rigid, hollow structure makes them suited to forming tracks for organelle transport (via motor proteins) and to forming the mitotic spindle and the core of cilia/flagella. Microfilaments are thin, solid strands of actin, only about 7 nm in diameter — their thinner, flexible structure suits roles in changing cell shape, cell crawling and pinching the cell in two (cytokinesis), rather than long-distance rigid transport tracks.

Bài tập luyện tập

A plant cell and an animal cell are both placed in pure water. Explain, with reference to cell structure, why the plant cell does not burst but an isolated animal cell would.

Lời giải chi tiết

In pure water (a hypotonic solution relative to the cytoplasm), water enters both cells by osmosis. In the plant cell, the rigid, freely-permeable **cellulose cell wall** resists the cell's expansion once the cell becomes fully turgid, so the wall's inward pressure balances further net water entry — the cell cannot burst. The animal cell has no cell wall (only a flexible cell surface membrane), so continued water entry would stretch the membrane beyond its limit, causing the cell to burst (lyse).

Bài tập luyện tập

Which combination of structures would you expect to find in a chloroplast but never in a mitochondrion?

(A) A double envelope membrane and its own circular DNA

(B) 70S ribosomes and a fluid matrix/stroma

(C) Thylakoids arranged in stacks called grana, containing chlorophyll

(D) An inner membrane folded to increase surface area

Lời giải chi tiết

Both organelles share a double envelope, their own circular DNA, 70S ribosomes and a fluid interior with a folded/internal membrane system for increasing surface area — but only chloroplasts have thylakoids stacked into grana carrying chlorophyll (the site of the light-dependent reactions). **(C)**.

Bài tập luyện tập

Explain why a large permanent vacuole helps support a non-woody (herbaceous) plant.

Lời giải chi tiết

The vacuole's cell sap has a lower (more negative) water potential than pure water, so water is drawn into the vacuole by osmosis across the tonoplast. As the vacuole fills, it pushes the cytoplasm and cell surface membrane outward against the rigid cellulose cell wall, generating **turgor pressure**. Many turgid cells packed together give non-woody tissues (e.g., leaves, young stems) mechanical rigidity and support, without needing wood or bone.

Bài tập luyện tập

Which statement correctly distinguishes TEM from SEM?

(A) TEM images the surface in 3-D; SEM images a thin internal section in 2-D

(B) TEM transmits electrons through an ultra-thin section for high-resolution internal detail; SEM scans electrons over a coated surface for a lower-resolution 3-D image

(C) TEM can view living cells; SEM cannot

(D) TEM and SEM produce images of identical resolution and dimensionality

Lời giải chi tiết

TEM: electrons pass through a very thin, stained section, giving a high-resolution 2-D view of internal ultrastructure. SEM: electrons are scanned across (and bounce off) a coated surface, giving a lower-resolution but 3-D surface image. Neither can view living cells. **(B)**.

Bài tập luyện tập

A biologist needs to isolate intact mitochondria from liver cells for a respiration experiment. Explain what would go wrong if the homogenising buffer were (a) at room temperature instead of ice-cold, and (b) hypotonic instead of isotonic.

Lời giải chi tiết

(a) At room temperature, enzymes (including hydrolytic enzymes released from ruptured lysosomes) remain highly active and would break down/damage the mitochondria before they can be isolated and studied, giving unreliable respiration results. **(b)** A hypotonic buffer has a higher water potential than the mitochondrial interior, so water would move into the mitochondria by osmosis, causing them to swell and potentially burst — destroying the double membrane needed for normal respiration, again giving unreliable results.

Bài tập luyện tập

Put the following organelles in the order they would be pelleted during differential centrifugation, starting with the first to sediment: ribosomes, mitochondria, nuclei, Golgi vesicles.

(A) Ribosomes, Golgi vesicles, mitochondria, nuclei

(B) Nuclei, mitochondria, Golgi vesicles, ribosomes

(C) Golgi vesicles, nuclei, ribosomes, mitochondria

(D) Mitochondria, nuclei, ribosomes, Golgi vesicles

Lời giải chi tiết

Sedimentation order depends on decreasing size/density: nuclei (largest/densest) first, then mitochondria, then Golgi vesicles/ER fragments, then ribosomes (smallest/least dense) last. **(B)**.

Bài tập luyện tập

An E. coli bacterium is roughly $2\ \mu$m long, while a typical animal mitochondrion is roughly $1{-}2\ \mu$m long. What does this size comparison support, and why?

Lời giải chi tiết

This comparison supports the **endosymbiotic theory** of mitochondrial origin: mitochondria are strikingly similar in size to free-living bacteria, and (as covered earlier) also share bacterial-like features — a circular DNA molecule and 70S ribosomes. Together, this evidence suggests mitochondria evolved from free-living aerobic bacteria that were engulfed by a larger ancestral cell and became permanent internal residents rather than being digested.

Bài tập luyện tập

Which of these is a correct description of a virus?

(A) A very small, single-celled prokaryote with a reduced number of organelles

(B) A non-cellular particle consisting of a protein capsid enclosing nucleic acid, sometimes with a lipid envelope and attachment proteins

(C) A eukaryotic cell that has lost its nucleus

(D) A fragment of a bacterial cell wall that has broken free

Lời giải chi tiết

A virus is not a cell at all — it is a non-cellular particle: a protein capsid enclosing a DNA or RNA core, sometimes surrounded by a lipid envelope with attachment proteins, and entirely dependent on a host cell to replicate. **(B)**.

Bài tập luyện tập

Explain why viruses, despite containing genetic material, are not classified as living organisms.

Lời giải chi tiết

Living organisms are defined by cellular structure and independent life processes (metabolism, growth, response, independent reproduction). Viruses lack cytoplasm, organelles and any metabolic machinery of their own, so they cannot carry out respiration or protein synthesis independently; critically, they cannot reproduce by themselves — they must hijack a host cell's ribosomes, enzymes and energy supply to replicate their nucleic acid and manufacture new capsid proteins. Because they cannot survive or reproduce independently of a host cell, they fall outside the accepted definition of a living organism.

Bài tập luyện tập

A photomicrograph of an animal cell is printed at a magnification of $\times 2000$. A mitochondrion in the image measures 2.4 mm long. Calculate the actual length of the mitochondrion in μm, and comment on whether it is realistic.

Lời giải chi tiết

$A = \dfrac{I}{M} = \dfrac{2.4\ \text{mm}}{2000} = 0.0012\ \text{mm} = 1.2\ \mu\text{m}$. This is realistic: real mitochondria are typically 0.5–$10\ \mu$m long.

Bài tập luyện tập

An electron micrograph (longitudinal section) shows a mitochondrion magnified $\times 24\,000$. Its inner membrane is folded into 8 visible cristae; each crista measures 14 mm long in the image, and the mitochondrion measures 6 mm across (width) in the same image. Modelling each crista as a simple flattened fold running the full width of the mitochondrion (two membrane faces per fold), estimate the total cristae membrane surface area shown in this section, in μm^2.

Lời giải chi tiết

Actual crista length $= \dfrac{14\text{ mm}}{24\,000} = 0.000583$ mm $= 0.583$ μm. Actual mitochondrion width $= \dfrac{6\text{ mm}}{24\,000} = 0.00025$ mm $= 0.25$ μm. Area of one crista (two membrane faces) $= 2 \times 0.583 \times 0.25 \approx 0.29$ μm^2. For 8 cristae: total $\approx 8 \times 0.29 =$ **2.3 □m²** — illustrating how folding the inner membrane multiplies the surface area available for respiration compared with a smooth, unfolded membrane of the same overall mitochondrial size.

Bài tập luyện tập

Which of the following would *not* be found in a bacterial (prokaryotic) cell?

(A) A cell surface membrane
(B) A mitochondrion
(C) Ribosomes
(D) Circular DNA

Lời giải chi tiết

Bacterial cells have a cell membrane, ribosomes (70S) and circular DNA, but no membrane-bound organelles at all — including no mitochondria (ATP is instead generated at the cell membrane). **(B)**.

Bài tập luyện tập

A plasmid carrying a gene for antibiotic resistance is transferred from one bacterium to another. Explain what a plasmid is and why this transfer matters medically.

Lời giải chi tiết

A **plasmid** is a small, circular piece of DNA, separate from the main bacterial chromosome, that can replicate independently and can carry additional genes (such as antibiotic resistance). Because plasmids can be transferred directly between bacteria (e.g., by conjugation), a resistance gene arising in one bacterium can spread rapidly through a bacterial population — and even between different bacterial species — which is a major mechanism behind the spread of antibiotic-resistant infections.

Bài tập luyện tập

Explain why the nuclear envelope is described as having pores, and state one type of molecule that passes through them.

Lời giải chi tiết

The nuclear envelope is perforated by **nuclear pores** — large protein-lined channels through both membranes of the envelope — that allow the controlled, selective passage of large molecules between the nucleus and the cytoplasm without these molecules having to cross the membrane by simple diffusion. Molecules that pass through include **messenger RNA** (moving out to the cytoplasm to be translated) and **ribosomal subunits** (assembled in the nucleolus, exported to the cytoplasm).

Bài tập luyện tập

A cell fragment is examined and found to contain a double membrane, a fluid interior with 70S ribosomes and circular DNA, but no thylakoids or grana. Which organelle is this most likely to be?

(A) Chloroplast
(B) Mitochondrion
(C) Nucleus
(D) Golgi body

Lời giải chi tiết

Double membrane, 70S ribosomes and circular DNA are shared by mitochondria and chloroplasts, but the absence of thylakoids/grana (and, implicitly, of chlorophyll) rules out the chloroplast. This is a **mitochondrion**. **(B)**.

Bài tập luyện tập

A microscope has a resolving power of 250 nm. Two structures in a cell are 180 nm apart. Explain what the observer would actually see, and why increasing the eyepiece magnification would not help.

Lời giải chi tiết

Because 180 nm is smaller than the microscope's resolving power of 250 nm, the two structures cannot be distinguished as separate points — they will appear as a single blurred point/region. Increasing the eyepiece magnification only enlarges this blurred image on the screen or eyepiece; it does not add any new information or detail, since resolution (not magnification) sets the limit on how much genuine detail can ever be seen. This is an example of **empty magnification**.

Bài tập luyện tập

Explain why an isolated mitochondrion, provided with oxygen and respiratory substrate in a suitable isotonic buffer, can continue to carry out aerobic respiration and produce ATP outside a living cell.

Lời giải chi tiết

The mitochondrion contains its own complete set of enzymes for the Krebs cycle (in the matrix) and the electron transport chain/ATP synthase (embedded in the folded inner membrane/cristae), along with its own circular DNA and 70S ribosomes to maintain some of these proteins. Because this machinery is self-contained within the organelle, an isolated mitochondrion supplied with oxygen and a respiratory substrate (such as pyruvate) in a suitable isotonic medium can continue aerobic respiration and generate ATP for some time, even outside a living cell.

Bài tập luyện tập

Which of the following lists structures in order from *smallest* to *largest* typical size?

(A) Virus, ribosome, mitochondrion, animal cell
(B) Ribosome, virus, animal cell, mitochondrion
(C) Animal cell, mitochondrion, virus, ribosome
(D) Mitochondrion, animal cell, ribosome, virus

Lời giải chi tiết

Typical sizes: ribosome ≈ 25 nm, virus ≈ 20–300 nm (comparable to or a little larger than a ribosome), mitochondrion ≈ 0.5–10 μm, animal cell ≈ 10–30 μm. From smallest to largest: virus/ribosome, mitochondrion, animal cell — matching option **(A)**, where the ribosome (smallest, ≈ 25 nm) is listed before the virus (up to a few hundred nm), then mitochondrion, then animal cell.

Bài tập luyện tập

State two structural differences between a fibrous protein forming a cell's cytoskeleton (e.g., actin) and a bacterial flagellum, in terms of what each is made of and how it moves the cell.

Lời giải chi tiết

A eukaryotic cytoskeletal microfilament is made of the protein **actin** and, together with myosin motor proteins, can generate localised contraction/movement of the cytoplasm (e.g., in cell crawling or cytokinesis) — it is not primarily used for swimming. A bacterial flagellum is made of a different protein, **flagellin**, arranged into a simple hollow helical filament, and is rotated like a propeller by a motor embedded in the cell wall/membrane, driving the whole bacterial cell through liquid — a far simpler structure than the microtubule-based (9+2) eukaryotic flagellum, and unrelated in structure to actin microfilaments.

Bài tập luyện tập

Convert 3.6 μm into nm, and 450 nm into mm. Show your working.

Lời giải chi tiết

3.6 μm $\times$ 1000 $=$ 3600 nm. 450 nm $\div$ 1000 $=$ 0.45 μm; 0.45 μm $\div$ 1000 $=$ 0.00045 mm. So 3.6 μm $=$ 3600 nm, and 450 nm $=$ 0.00045 mm.

Bài tập luyện tập

An image of a chloroplast is 84 mm long at a magnification of $\times 12\,000$. A second image of the same chloroplast, taken with a different microscope, is 56 mm long. Calculate the magnification of the second image.

Lời giải chi tiết

First, find the actual length from the first image: $A = \dfrac{84 \text{ mm}}{12\,000} = 0.007$ mm $= 7$ μm. This actual length is the same in both images (same chloroplast). For the second image: $M = \dfrac{I}{A} = \dfrac{56 \text{ mm}}{7\ \mu\text{m}}$.

Convert 56 mm to μm: $56\,000$ μm. $M = \dfrac{56\,000}{7} =$ **8000**$\times$.

Bài tập luyện tập

Explain why light microscopy remains useful in biology despite its far lower resolution than electron microscopy.

Lời giải chi tiết

Light microscopy can image **living cells**, in real time, without a vacuum or extensive chemical fixation — allowing observation of ongoing processes such as cell division, cytoplasmic streaming or the movement of live organisms, and permitting the use of specific stains and fluorescent labels in living tissue. Electron microscopy, though far higher in resolution, requires the specimen to be dead, dehydrated and held in a vacuum, so it cannot show dynamic, living processes — the two techniques are complementary rather than one simply replacing the other.

Bài tập luyện tập

A tissue sample yields the following pellets in order at increasing centrifuge speed: Pellet 1, Pellet 2, Pellet 3, Pellet 4. A researcher confirms Pellet 2 contains structures with a double membrane, cristae and their own DNA. Identify Pellet 2, and name one organelle you would expect to find in Pellet 1 instead.

Lời giải chi tiết

Pellet 2 (the second to sediment, at a moderate speed) contains structures with a double membrane, cristae and their own DNA — this describes **mitochondria**. Pellet 1 (sedimenting first, at the lowest speed) would contain the largest, densest structures — the **nuclei**.

Biological Molecules

AS Level

Mục tiêu Unit: Cấu trúc phân tử nước và ý nghĩa sinh học của từng tính chất; nguyên tắc chung phản ứng trùng ngưng (condensation) và thuỷ phân (hydrolysis); cấu trúc và chức năng carbohydrate (đơn, đôi, đa đường: tinh bột, glycogen, cellulose); bốn bậc cấu trúc protein và ví dụ collagen/haemoglobin; lipid (triglyceride, phospholipid) và vai trò sinh học; các phép thử sinh hoá nhận biết đường khử, đường không khử, tinh bột, protein, lipid, vitamin C; nguyên lý sắc ký giấy và tính giá trị R_f.

2.1 Water

2.1.1 Polarity and hydrogen bonding

Khái niệm cốt lõi

A water molecule (H_2O) is bent, with oxygen far more electronegative than hydrogen, so the shared electrons sit closer to the oxygen atom. This gives water a permanent **dipole**: oxygen carries a partial negative charge (δ^-), each hydrogen a partial positive charge (δ^+). Water is therefore a **polar molecule**. The δ^+ hydrogen of one water molecule is weakly attracted to the δ^- oxygen of a neighbouring molecule, forming a **hydrogen bond** — individually weak, but present in vast numbers between water molecules, giving liquid water an extensive, constantly re-forming network of interactions.

VN **GIẢI THÍCH TIẾNG VIỆT**

Phân tử nước có hình chữ V, oxy có độ âm điện lớn hơn hydro nên electron dùng chung bị kéo lệch về phía oxy, tạo ra **điện tích một phần**: oxy mang δ^-, mỗi hydro mang δ^+ — nước là phân tử **phân cực**. **Liên kết hydro** hình thành giữa H mang δ^+ của phân tử này với O mang δ^- của phân tử bên cạnh. Đây là nền tảng cho mọi tính chất đặc biệt của nước trình bày dưới đây.

2.1.2 High specific heat capacity

A large amount of thermal energy must be absorbed to break hydrogen bonds and raise water's temperature (and a large amount is released as it cools), so water resists rapid temperature change. **Biological significance:** this buffers the internal temperature of organisms and of aquatic habitats against sudden fluctuation, protecting enzyme-catalysed reactions that are sensitive to temperature change.

2.1.3 High latent heat of vaporisation

Evaporating water requires breaking many hydrogen bonds, so a large amount of energy is removed from the surroundings for every gram of water that evaporates. **Biological significance:** sweating and panting cool the body substantially using only a small volume of water; transpiration similarly cools leaves exposed to direct sunlight.

2.1.4 Cohesion and surface tension

Hydrogen bonding makes water molecules cling strongly to one another (**cohesion**) and to other polar surfaces such as the walls of xylem vessels (**adhesion**). At an air–water interface, cohesive forces pull surface molecules inward, creating **surface tension** — an elastic "skin" effect. **Biological significance:** cohesion between water molecules allows an unbroken column of water to be pulled up through the xylem of tall plants (the transpiration stream, covered in the transport unit); surface tension allows small organisms (e.g., pond skaters) to rest or move on the water surface.

2.1.5 Water as a solvent

Water's polarity lets it surround and dissolve other polar or ionic substances, forming hydration shells around ions (e.g., Na^+, Cl^-) and polar molecules (e.g., glucose). **Biological significance:** water is the medium in which almost all metabolic reactions occur, and the medium in which respiratory gases, ions, glucose and other solutes are transported around organisms (e.g., in blood plasma).

2.1.6 Density anomaly of ice

In liquid water, hydrogen bonds are constantly breaking and re-forming, allowing molecules to pack relatively closely. In ice, each molecule is locked into exactly four fixed hydrogen bonds arranged in an open hexagonal lattice, holding molecules further apart than in the liquid — ice is therefore about 9% *less* dense than liquid water and floats. **Biological significance:** floating ice insulates the liquid water beneath it, allowing aquatic organisms to survive through winter instead of the whole body of water freezing solid from the bottom up.

Property	Biological significance
High specific heat capacity	Buffers internal/environmental temperature against rapid change
High latent heat of vaporisation	Efficient evaporative cooling (sweating, transpiration) with little water lost
Cohesion / surface tension	Supports the transpiration stream; supports small organisms on water surfaces
Universal solvent	Medium for metabolic reactions and solute transport
Ice less dense than water	Ice floats, insulating water below and allowing aquatic life to survive winters

(!) Lỗi thường gặp: "Chất rắn luôn đặc hơn chất lỏng cùng loại" — sai đối với nước. Trong nước đá, mỗi phân tử bị khoá cố định trong đúng 4 liên kết hydro tạo mạng tinh thể lục giác cồng kềnh, khiến các phân tử cách xa nhau hơn so với nước lỏng. Do đó băng *nổi* trên nước lỏng — một tính chất bất thường nhưng quan trọng về mặt sinh thái.

2.2 Monomers, Polymers and the Condensation--Hydrolysis Principle

Khái niệm cốt lõi

Large biological molecules (**polymers**) are built from repeating smaller subunits (**monomers**). Monomers are joined by **condensation reactions**: a covalent bond forms between two monomers, and one molecule of water is released for every bond formed. The reverse reaction, **hydrolysis**, breaks a covalent bond by adding back a molecule of water across it, regenerating the two separate monomers. This single principle underlies the assembly and breakdown of carbohydrates, proteins and (with a small modification) lipids.

VN **GIẢI THÍCH TIẾNG VIỆT**

Phản ứng **trùng ngưng (condensation)**: hai monomer nối với nhau bằng liên kết cộng hoá trị, **giải phóng** một phân tử nước. Phản ứng **thuỷ phân (hydrolysis)**: ngược lại — **thêm nước** vào để phá vỡ liên kết, tách polymer thành các monomer.

2.3 Carbohydrates

2.3.1 Monosaccharides

Khái niệm cốt lõi

Monosaccharides are single-sugar units with general formula $(CH_2O)_n$. The most important hexose (6-carbon) sugar is **glucose** ($C_6H_{12}O_6$); **fructose** and **galactose** are structural isomers of glucose — same molecular formula, different arrangement of atoms. **Ribose** and **deoxyribose** are pentose (5-carbon) sugars forming part of RNA and DNA nucleotides respectively.
Glucose can close into a ring in two slightly different orientations around carbon 1: in **α-glucose** the hydroxyl group on carbon 1 points below the plane of the ring; in **β-glucose** it points above. This apparently tiny difference has enormous structural consequences (see polysaccharides, below).

α-glucose and β-glucose differ only in the orientation of the hydroxyl group on carbon 1 — the basis of the structural difference between starch/glycogen (α) and cellulose (β).

VN **GIẢI THÍCH TIẾNG VIỆT**

Monosaccharide là đường đơn (glucose, fructose, galactose — cùng công thức $C_6H_{12}O_6$ nhưng khác cách sắp xếp nguyên tử, là đồng phân cấu trúc của nhau). **α-glucose** và **β-glucose** chỉ khác nhau ở hướng nhóm $-$OH tại carbon số 1 (hướng xuống với α, hướng lên với β) — nhưng chính khác biệt nhỏ này quyết định tinh bột/glycogen (α) khác cellulose (β) hoàn toàn về tính chất.

2.3.2 Glycosidic bonds and disaccharides

Two monosaccharides join by a condensation reaction between hydroxyl groups on adjacent carbons, forming a **glycosidic bond** and releasing one water molecule.

Disaccharide	Monomers	Notes
Maltose	α-glucose + α-glucose	Reducing sugar; formed during starch digestion
Sucrose	α-glucose + β-fructose	Non-reducing sugar; transported in plant phloem
Lactose	β-galactose + α-glucose	Reducing sugar; the sugar found in milk

VN **GIẢI THÍCH TIẾNG VIỆT**

Hai monosaccharide liên kết bằng **liên kết glycosidic** (qua phản ứng trùng ngưng, giải phóng nước) tạo thành **disaccharide**: maltose (glucose–glucose), sucrose (glucose–fructose, đường ăn hàng ngày, *không phải* đường khử), lactose (galactose–glucose, đường trong sữa).

2.3.3 Polysaccharides: starch, glycogen and cellulose

Khái niệm cốt lõi

Starch is the plant storage polysaccharide, made of two types of α-glucose chain: **amylose** (unbranched, coiled into a helix by α-1,4 glycosidic bonds) and **amylopectin** (branched, with additional α-1,6 bonds at branch points). **Glycogen**, the animal/fungal storage polysaccharide, has the same basic α-1,4/α-1,6 bonding pattern as amylopectin but is far more extensively branched. **Cellulose** is made entirely of β-glucose monomers linked by β-1,4 glycosidic bonds; because each successive glucose is rotated 180° relative to its neighbour, the chains run straight (rather than coiling), allowing many parallel chains to be cross-linked by hydrogen bonds into bundles called **microfibrils**, which are extremely strong under tension. **Chitin**, structurally similar to cellulose but built from N-acetylglucosamine (a nitrogen-containing glucose derivative), forms fungal cell walls and arthropod exoskeletons.

Polysaccharide	Monomer / bond	Branching	Structure–function link
Amylose (starch)	α-glucose, α-1,4	Unbranched	Coils into a compact helix; compact storage, insoluble (no osmotic effect)
Amylopectin (starch)	α-glucose, α-1,4 + α-1,6	Moderately branched	Extra ends allow moderately fast glucose release
Glycogen	α-glucose, α-1,4 + α-1,6	Highly branched	Many free ends for very rapid glucose mobilisation
Cellulose	β-glucose, β-1,4	Unbranched, straight	H-bonded microfibrils give high tensile strength

Ví dụ mẫu · Worked example

Explain why glycogen is better suited than starch to being rapidly mobilised for energy in animals.

Glycogen is even more highly branched than amylopectin (the branched component of starch). Each branch point creates an additional free end from which hydrolytic enzymes can remove glucose units; more branching means more free ends, so many enzyme molecules can act simultaneously across the whole molecule, releasing glucose far more rapidly than a less-branched or unbranched chain — matching the fast, fluctuating energy demands of animal metabolism.

VN **GIẢI THÍCH TIẾNG VIỆT**

Sự khác biệt cốt lõi giữa tinh bột/glycogen và cellulose là hướng liên kết glycosidic: α-1,4 (tinh

bột, glycogen) so với β-1,4 (cellulose). Enzyme tiêu hoá của người chỉ cắt được liên kết α, nên ta tiêu hoá được tinh bột nhưng không tiêu hoá được cellulose (chất xơ) dù cả hai đều chỉ là chuỗi glucose. Glycogen phân nhánh nhiều hơn tinh bột thực vật để huy động glucose nhanh hơn khi cơ thể cần năng lượng gấp.

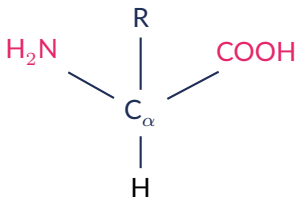
(!) Lỗi thường gặp: Đừng nhầm "không tiêu hoá được cellulose" với "cellulose vô dụng đối với con người". Cellulose (chất xơ) không bị enzyme tiêu hoá của người phân giải, nhưng vẫn có vai trò quan trọng: tạo khối phân, kích thích nhu động ruột, và là cơ chất cho vi khuẩn có lợi trong ruột già lên men.

2.4 Proteins

2.4.1 Amino acid structure and the peptide bond

Khái niệm cốt lõi

Every one of the 20 standard **amino acids** shares the same general structure: a central carbon atom bonded to (1) an amino group ($-NH_2$), (2) a carboxyl group ($-COOH$), (3) a hydrogen atom, and (4) a variable **R group** that gives each amino acid its distinct chemical identity (some R groups are non-polar/hydrophobic, some polar, some acidic, some basic). Two amino acids join by a condensation reaction between the carboxyl group of one and the amino group of the next, forming a **peptide bond** and releasing one water molecule; a chain of many amino acids joined this way is a **polypeptide**.



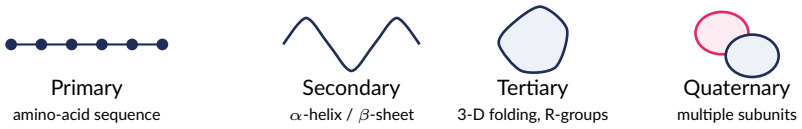
General structure of an amino acid: a central carbon bonded to an amino group, a carboxyl group, a hydrogen atom, and a variable R group.

VN **GIẢI THÍCH TIẾNG VIỆT**

Mỗi amino acid có chung một "khung": carbon trung tâm gắn với nhóm amino ($-NH_2$), nhóm carboxyl ($-COOH$), một nguyên tử H, và một **nhóm R** riêng biệt quyết định loại amino acid. Hai amino acid nối với nhau bằng **liên kết peptide** (qua phản ứng trùng ngưng, giải phóng nước) tạo thành chuỗi **polypeptide**.

2.4.2 The four levels of protein structure

Primary structure — the specific sequence of amino acids in the polypeptide chain, held together by peptide bonds.
Secondary structure — local, regular folding of the backbone into an α**-helix** (a coil) or a β**-pleated sheet** (folded, extended strands), stabilised by hydrogen bonds between the C=O and N–H groups of the peptide backbone.
Tertiary structure — the overall three-dimensional folding of a single polypeptide chain, stabilised by interactions between R groups: hydrogen bonds, ionic bonds (between oppositely charged R groups), disulfide bonds (covalent, between two cysteine R groups) and hydrophobic interactions (non-polar R groups clustering away from water).
Quaternary structure — the association of two or more polypeptide chains (subunits) into a single functional protein, sometimes together with a non-protein prosthetic group (e.g. a haem group).



The four levels of protein structure, each built upon the one before it.

VN **GIẢI THÍCH TIẾNG VIỆT**
Bốn bậc cấu trúc protein: **bậc 1** là trình tự amino acid (liên kết peptide); **bậc 2** là các kiểu gấp cục bộ (α-helix, β-sheet) nhờ liên kết hydro giữa các nguyên tử khung; **bậc 3** là hình dạng 3 chiều tổng thể của *một* chuỗi polypeptide, giữ vững nhờ liên kết hydro, liên kết ion, cầu disulfide và tương tác kỵ nước giữa các nhóm R; **bậc 4** là sự kết hợp của *nhiều* chuỗi polypeptide (ví dụ haemoglobin gồm 4 chuỗi $+$ nhóm heme).

(!) Lỗi thường gặp: Đừng nhầm liên kết **peptide** (bậc 1, cộng hoá trị, rất bền) với các liên kết **yếu** giữ bậc 2/3/4 (hydro, ion, kỵ nước) — khi protein bị **biến tính** (nhiệt độ cao, pH cực đoan), chỉ các liên kết yếu này bị phá vỡ, trình tự amino acid (bậc 1) vẫn nguyên vẹn. Cầu **disulfide** tuy là liên kết cộng hoá trị (bền hơn liên kết yếu khác) nhưng vẫn có thể bị phá vỡ trong điều kiện biến tính mạnh.

2.4.3 Fibrous proteins: collagen

Khái niệm cốt lõi

Collagen is a fibrous, structural protein: three polypeptide chains, each itself coiled, wind around one another into a tightly-wound **triple helix**. Hydrogen bonds between the three chains hold the helix together, and covalent cross-links form between adjacent collagen molecules lying side by side, bundling them into strong **fibrils**. This gives collagen very high tensile strength (resistance to stretching) but little flexibility, well suited to tendons, ligaments, skin and the walls of blood vessels.

VN **GIẢI THÍCH TIẾNG VIỆT**
Collagen là protein sợi (fibrous): 3 chuỗi polypeptide xoắn lại thành **xoắn ba (triple helix)**, giữ chặt nhờ liên kết hydro giữa các chuỗi, cùng các liên kết cộng hoá trị nối các phân tử collagen liền kề thành bó sợi (fibril) rất bền. Cấu trúc này cho độ bền kéo cao — phù hợp với gân, dây chằng, da, thành mạch máu.

2.4.4 Globular proteins: haemoglobin

Khái niệm cốt lõi

Haemoglobin is a globular, transport protein with quaternary structure: four polypeptide chains (two α-chains, two β-chains in adult haemoglobin), each folded into a compact tertiary structure with hydrophilic R groups on the outside (water-soluble) and hydrophobic R groups clustered inside. Each of the four chains carries one non-protein **haem group**, containing an Fe^{2+} ion that reversibly binds one molecule of oxygen — so each haemoglobin molecule can carry up to **four** oxygen molecules.

VN **GIẢI THÍCH TIẾNG VIỆT**

Haemoglobin là protein cầu (globular), có bậc 4: gồm 4 chuỗi polypeptide (2 chuỗi α, 2 chuỗi β), mỗi chuỗi mang một nhóm **heme** chứa ion Fe^{2+} liên kết thuận nghịch với một phân tử O_2 — vì vậy mỗi phân tử haemoglobin vận chuyển được tối đa 4 phân tử oxy.

Ví dụ mẫu · Worked example

Sickle-cell haemoglobin (HbS) differs from normal haemoglobin (HbA) by a single amino acid substitution at position 6 of the β-chain: glutamic acid (acidic, hydrophilic R group) is replaced by valine (non-polar, hydrophobic R group). Explain how this single substitution can affect the protein's tertiary/quaternary structure and function.

Glutamic acid's charged, hydrophilic R group would normally sit on the outer surface of the folded chain, in contact with water. Valine's non-polar R group instead creates a hydrophobic patch on the surface of the β-chain. Under low-oxygen conditions, these hydrophobic patches on adjacent haemoglobin molecules stick together (hydrophobic interactions), causing haemoglobin molecules to aggregate into long, rigid fibres. This distorts the normal biconcave shape of the red blood cell into a rigid "sickle" shape, which is less flexible, carries oxygen less efficiently, and can block narrow capillaries — illustrating how a change to just one amino acid in the primary structure can propagate into altered tertiary/quaternary structure and drastically altered function.

	Collagen (fibrous)	**Haemoglobin (globular)**
Shape	Long, rope-like triple helix	Compact, roughly spherical
Solubility	Insoluble in water	Soluble in water
R-group arrangement	Regular, repetitive, exposed	Hydrophilic outside, hydrophobic inside
Role	Structural (mechanical strength)	Transport (carries O_2)

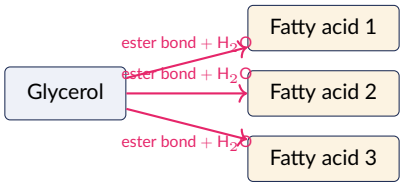
2.5 Lipids

2.5.1 Triglycerides

Khái niệm cốt lõi

A **triglyceride** forms when one molecule of **glycerol** (a three-carbon alcohol with three hydroxyl groups) undergoes condensation with three **fatty acid** molecules (long hydrocarbon chains ending in a carboxyl group), forming three **ester bonds** and releasing three water molecules. A fatty acid is **saturated** if it has no carbon–carbon double bonds (straight chain, packs tightly,

solid at room temperature — typical of animal fats); it is **unsaturated** if it has one or more C=C double bonds (each introduces a rigid kink, preventing tight packing — typical of plant oils, liquid at room temperature).



Triglyceride formation: one glycerol + three fatty acids, joined by three ester bonds, releasing three water molecules in total.

VN **GIẢI THÍCH TIẾNG VIỆT**

Triglyceride $= 1$ glycerol $+3$ acid béo, liên kết bằng 3 liên kết **ester** (giải phóng 3 phân tử nước). Acid béo **bão hoà** (không có liên kết đôi C=C) có mạch thẳng, xếp khít, thường ở thể rắn ở nhiệt độ phòng (mỡ động vật). Acid béo **không bão hoà** (có ≥ 1 liên kết đôi) bị "gãy khúc", xếp lỏng lẻo, thường ở thể lỏng (dầu thực vật).

2.5.2 Phospholipids

Khái niệm cốt lõi

A **phospholipid** is built like a triglyceride, but one fatty acid is replaced by a phosphate-containing group. This gives the molecule a hydrophilic (water-loving) **phosphate head** and two hydrophobic (water-fearing) **fatty acid tails** — an amphipathic molecule. In water, phospholipids spontaneously arrange into a **bilayer**, tails facing inward away from water, heads facing outward into the surrounding water on both sides — the fundamental architecture of every cell membrane (developed further in the membranes unit).

VN **GIẢI THÍCH TIẾNG VIỆT**

Phospholipid giống triglyceride nhưng một acid béo được thay bằng nhóm **phosphate**. Điều này tạo ra đầu **ưa nước (phosphate)** và hai đuôi **kỵ nước (acid béo)**. Trong nước, phospholipid tự sắp xếp thành **lớp kép (bilayer)** — nền tảng cấu trúc của mọi màng tế bào.

2.5.3 Roles of lipids

Energy storage — lipids contain more energy per gram than carbohydrates (roughly twice as much), because their hydrocarbon-rich structure has many more C–H bonds to be oxidised. **Thermal insulation** — subcutaneous fat reduces heat loss. **Waterproofing** — waxy/lipid layers (e.g. leaf cuticle, skin sebum) reduce water loss. **Membrane structure** — phospholipids form the bilayer of all cell membranes. **Hormones** — steroid hormones (e.g. oestrogen, testosterone) are lipid-derived and can diffuse directly through membranes.

Ví dụ mẫu · Worked example

A 2.0 g sample of pure triglyceride is completely oxidised, releasing 75 kJ of energy. A 2.0 g sample of pure starch releases about 34 kJ. Explain, in terms of chemical structure, why the triglyceride releases roughly twice as much energy per gram.

Triglyceride molecules are built mostly of long hydrocarbon fatty-acid chains, rich in **C–H bonds** and containing relatively little oxygen; carbohydrates such as starch already contain proportionally more oxygen (and correspondingly fewer C–H bonds per unit mass). Because C–H bonds release more energy on oxidation than bonds to oxygen already present, the more reduced (hydrogen-rich, oxygen-poor) triglyceride structure yields substantially more energy per gram when fully oxidised.

Ví dụ mẫu · Worked example

A triglyceride is formed from glycerol ($C_3H_8O_3$, molar mass 92 g/mol) and three molecules of palmitic acid ($C_{16}H_{32}O_2$, molar mass 256 g/mol each). Calculate the molar mass of the resulting triglyceride, and the percentage of that mass contributed by the fatty acid portion.

Total mass of reactants $= 92 + 3(256) = 92 + 768 = 860$ g/mol. Three ester bonds form, releasing 3 water molecules ($3 \times 18 = 54$ g/mol). Triglyceride molar mass $= 860 - 54 =$ **806** g/mol. Fatty-acid contribution (mass of the 3 fatty acids, ignoring the water lost from them for a simple estimate) $\approx \dfrac{768}{806} \times 100 =$ **95.3**% — showing that the great majority of a triglyceride's mass (and hence its stored chemical energy) comes from its fatty acid tails, not its glycerol backbone.

2.6 Biochemical Tests

2.6.1 Benedict's test for reducing sugars

Khái niệm cốt lõi

Add an equal volume of **Benedict's reagent** (blue, alkaline copper(II) sulfate solution) to the sample and heat in a boiling water bath for about 5 minutes. A **reducing sugar** (all monosaccharides, and disaccharides such as maltose and lactose) reduces the blue Cu^{2+} ions to a brick-red precipitate of copper(I) oxide (Cu_2O). The colour progresses blue → green → yellow → orange → brick-red as the concentration of reducing sugar increases — making the test **semi-quantitative** by eye.

Ví dụ mẫu · Worked example

Describe a method to obtain a more precise, semi-quantitative estimate of the concentration of a reducing sugar solution using Benedict's test.

Prepare a dilution series of the unknown sample (e.g., undiluted, $\times 2$, $\times 4$, $\times 8$, $\times 16$ dilution), and add the *same* excess volume of Benedict's reagent to an equal volume of each dilution; heat all tubes for the same fixed time in a boiling water bath. Record the most dilute sample that still gives a positive (brick-red) result — the greater the dilution needed before the test turns negative, the higher the original concentration of reducing sugar. (Alternatively, filtering off and weighing the precipitate, or measuring the colour with a colorimeter and comparing absorbance to a calibration curve of known concentrations, gives a quantitative result.)

2.6.2 Test for non-reducing sugars

Khái niệm cốt lõi

Sucrose is a **non-reducing sugar** — it gives a negative (blue) result with Benedict's reagent directly. To test for it: first boil a fresh sample with dilute hydrochloric acid (this hydrolyses the glycosidic bond, releasing the constituent monosaccharides), then neutralise with sodium hydrogencarbonate (or sodium hydroxide), and finally carry out the standard Benedict's test. A positive (brick-red) result *after* hydrolysis, when the original (unhydrolysed) sample gave a negative result, confirms the presence of a non-reducing sugar.

2.6.3 Iodine test for starch

Add iodine dissolved in potassium iodide solution to the sample. A **positive** result is a **blue-black** colour, caused by iodine molecules fitting inside the coiled helix of amylose. A negative result remains yellow-brown (the original colour of the iodine solution).

2.6.4 Biuret test for protein

Add sodium hydroxide solution, then add dilute copper(II) sulfate solution drop by drop (or add biuret reagent directly). A **positive** result is a **purple/lilac** colour, produced when Cu^{2+} ions form a coloured complex with the nitrogen atoms of peptide bonds (at least two peptide bonds are needed for a clear positive, so free amino acids and dipeptides give a very weak or negative result). A negative result stays blue.

2.6.5 Emulsion test for lipids

Shake the sample vigorously with ethanol, allowing any lipid present to dissolve in the ethanol; then pour this ethanol layer into a test tube of water. A **positive** result is a **cloudy white emulsion** (fine droplets of lipid scattering light as they come out of solution in water); a negative result gives a clear solution.

Test	Method (brief)	Positive result
Benedict's (reducing sugar)	Add reagent; heat in boiling water bath	Blue → brick-red precipitate
Non-reducing sugar	Boil with dilute HCl, neutralise, then Benedict's	Brick-red *only after* hydrolysis
Iodine (starch)	Add iodine/potassium iodide solution	Blue-black
Biuret (protein)	Add NaOH, then dilute $CuSO_4$	Purple/lilac
Emulsion (lipid)	Shake with ethanol, add to water	White, cloudy emulsion
DCPIP (vitamin C)	Add sample dropwise to DCPIP solution	Blue DCPIP decolourises

VN **GIẢI THÍCH TIẾNG VIỆT**

Bảng các phép thử sinh hoá cần nhớ chính xác **kết quả dương tính**: Benedict's (đường khử) → đỏ gạch; đường không khử phải **thuỷ phân bằng HCl, trung hoà**, rồi mới thử Benedict's; iodine (tinh bột) → xanh đen; biuret (protein) → tím; nhũ tương (lipid) → trắng đục; DCPIP (vitamin C) → mất màu xanh của DCPIP.

2.6.6 DCPIP test for vitamin C

Khái niệm cốt lõi

DCPIP (dichlorophenolindophenol) is a blue dye that turns colourless (or pale pink) when it is **reduced** — and vitamin C (ascorbic acid) is a reducing agent that can decolourise it. To make the test **quantitative**: add the sample *dropwise* to a fixed, small volume of DCPIP solution, swirling after each drop, until the blue colour just disappears; record the volume (or number of drops) of sample needed.

The volume of sample needed to decolourise a fixed volume of DCPIP is **inversely** related to vitamin C concentration: a *small* volume needed to decolourise the DCPIP means the sample is *highly concentrated* in vitamin C (each drop delivers a lot of reducing power); a *large* volume needed means the sample is more *dilute* in vitamin C.

Ví dụ mẫu · Worked example

Two fruit juice samples are each added dropwise to 1 cm^3 of the same DCPIP solution until it just decolourises. Sample A requires 0.80 cm^3; sample B requires 2.40 cm^3. Which sample has the higher vitamin C concentration, and by what factor?

Because a *smaller* volume of sample is needed to decolourise the same amount of DCPIP when the sample is *more* concentrated in vitamin C, Sample A (requiring only 0.80 cm^3) is more concentrated than Sample B (requiring 2.40 cm^3). Vitamin C concentration is inversely proportional to the volume needed, so the ratio of concentrations is $\frac{2.40}{0.80} = 3$: Sample A is **three times** more concentrated in vitamin C than Sample B.

VN **GIẢI THÍCH TIẾNG VIỆT**

Trong phép thử DCPIP, thể tích mẫu cần dùng để làm mất màu DCPIP **tỉ lệ nghịch** với nồng độ vitamin C: cần **ít** mẫu hơn để làm mất màu ⇒ mẫu đó **đậm đặc** vitamin C hơn; cần **nhiều** mẫu hơn ⇒ mẫu đó **loãng** vitamin C hơn. Đây là điểm học sinh rất hay nhớ ngược — cần ghi nhớ chính xác chiều quan hệ này.

Ví dụ mẫu · Worked example

A sample gives the following results: iodine test negative, biuret test positive (purple), emulsion test positive (white, cloudy). What does the sample contain, and what does it *not* contain?

Biuret positive (purple) ⇒ contains **protein**. Emulsion positive (cloudy white) ⇒ contains **lipid**. Iodine negative (stays yellow-brown, no blue-black) ⇒ **no starch** is present. The sample therefore contains both protein and lipid, but not starch.

2.7 Chromatography

2.7.1 Principle and the R_f value

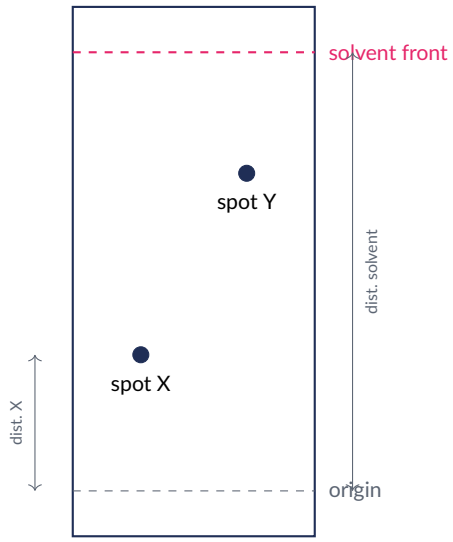
Khái niệm cốt lõi

Paper (or thin-layer) chromatography separates a mixture of substances based on their differing solubility in, and affinity for, two phases: a **stationary phase** (the paper or thin layer) and a **mobile phase** (a solvent that moves through/along the stationary phase). A small spot of the sample is placed near one edge of the paper (the **origin**, marked in pencil, kept above

the level of the solvent), and the solvent is allowed to travel up (or along) the paper. Different substances in the mixture partition between the two phases to different extents and are carried different distances, separating into distinct spots. Once the solvent has nearly reached the top (the **solvent front**), the paper is removed and the distances measured to calculate the R_f **value** (retention factor) for each spot:

$$R_f = \frac{\text{distance moved by the solute (spot centre from origin)}}{\text{distance moved by the solvent front (from origin)}}$$

Under identical conditions (same solvent, same paper, same temperature), a given substance always produces the same R_f value, so an unknown spot can be identified by comparing its R_f with the R_f values of known reference substances run on the same chromatogram.



A chromatogram: distances are measured from the origin to each spot's centre, and from the origin to the solvent front.

Ví dụ mẫu · Worked example

On a chromatogram, the solvent front travels 8.0 cm from the origin. An unknown pigment spot travels 6.0 cm from the origin. Calculate its R_f value.

$$R_f = \frac{6.0}{8.0} = \mathbf{0.75}.$$

Ví dụ mẫu · Worked example

Four amino acids are run on a chromatogram alongside an unknown mixture, using the same solvent. The solvent front travels 15.0 cm. Known R_f values: glycine 0.26, alanine 0.38, leucine 0.73, lysine 0.14. The unknown mixture produces two spots, at 5.7 cm and 11.0 cm from the origin. Identify the two amino acids in the unknown mixture.

Calculate R_f for each unknown spot: spot 1, $R_f = \dfrac{5.7}{15.0} = 0.38$; spot 2, $R_f = \dfrac{11.0}{15.0} \approx 0.73$. Comparing with the known values: $R_f = 0.38$ matches **alanine**, and $R_f \approx 0.73$ matches **leucine**.

VN **GIẢI THÍCH TIẾNG VIỆT**

Sắc ký giấy tách hỗn hợp dựa trên độ hoà tan/ái lực khác nhau của từng chất với **pha tĩnh** (giấy) và **pha động** (dung môi di chuyển). Giá trị $R_f = \dfrac{\text{khoảng cách di chuyển của chất tan}}{\text{khoảng cách di chuyển của dung môi}}$ là hằng số đặc trưng cho mỗi chất trong cùng điều kiện thí nghiệm (cùng dung môi, cùng nhiệt độ), nên có thể dùng để **nhận diện chất chưa biết** bằng cách so sánh với R_f của chất đã biết chạy cùng bản sắc ký.

(!) Lỗi thường gặp: Luôn nhớ đặt vết chấm mẫu (origin) **trên** mực dung môi trong bình sắc ký — nếu vết mẫu bị ngập trong dung môi, các chất sẽ hoà tan trực tiếp vào dung môi thay vì di chuyển dần theo pha động, làm hỏng thí nghiệm. Ngoài ra, giá trị R_f chỉ so sánh được khi hai bản sắc ký dùng **cùng loại dung môi và cùng nhiệt độ**.

2.8 Practice Questions

Bài tập luyện tập

Which property of water is directly responsible for evaporative cooling (e.g., sweating) removing a large amount of heat using only a small volume of water?

(A) High density
(B) High latent heat of vaporisation
(C) Low specific heat capacity
(D) Low surface tension

Lời giải chi tiết

A high latent heat of vaporisation means a large amount of thermal energy must be absorbed (from the body/skin) to break the hydrogen bonds and evaporate each gram of water, so only a small volume of sweat needs to evaporate to remove a large quantity of heat. **(B)**.

Bài tập luyện tập

Explain, in terms of hydrogen bonding, why ice is less dense than liquid water.

Lời giải chi tiết

In ice, each water molecule is held in exactly four fixed hydrogen bonds, arranged in a rigid, open hexagonal lattice that keeps molecules further apart, on average, than in the liquid. In liquid water, hydrogen bonds are constantly breaking and re-forming, allowing molecules to pack more closely together on average. Because the same mass of water occupies a larger volume as ice, ice is less dense than liquid water and floats.

Bài tập luyện tập

Which statement correctly describes a condensation reaction?

(A) A covalent bond is broken by adding a water molecule
(B) A covalent bond forms between two monomers, releasing a water molecule
(C) Two monomers are joined without any change in mass
(D) Water is added to a polymer to release its monomers

Lời giải chi tiết

Condensation joins two monomers with a new covalent bond and releases one water molecule per bond formed; the reverse process (adding water to break a bond) is hydrolysis. **(B)**.

Bài tập luyện tập

Distinguish α-glucose from β-glucose, and explain briefly why this difference matters biologically.

Lời giải chi tiết

α-glucose and β-glucose are structural isomers that differ only in the orientation of the hydroxyl group on carbon 1: it points below the plane of the ring in α-glucose and above the plane in β-glucose. This small difference matters enormously: polymers of α-glucose (starch, glycogen) coil into compact helices ideal for storage and are hydrolysed by human digestive enzymes, whereas polymers of β-glucose (cellulose) form straight, hydrogen-bonded chains ideal for structural strength, and cannot be hydrolysed by human digestive enzymes.

Bài tập luyện tập

Which disaccharide is formed from α-glucose and β-fructose, and is classified as a non-reducing sugar?

(A) Maltose
(B) Lactose
(C) Sucrose
(D) Cellobiose

Lời giải chi tiết

Sucrose is formed from α-glucose and β-fructose and, unlike maltose or lactose, does not give a positive Benedict's test directly (non-reducing sugar). **(C)**.

Bài tập luyện tập

Explain why glycogen is more extensively branched than amylopectin, and how this relates to their different biological roles.

Lời giải chi tiết

Both glycogen and amylopectin are α-1,4-linked glucose chains with α-1,6 branch points, but glycogen has many more branch points. Each branch creates an additional free (non-reducing) end at which enzymes can add or remove glucose units, so more branching allows glucose to be added to, or removed from, the molecule more rapidly at many points simultaneously. Animals (glycogen) typically have more rapidly fluctuating energy demands (e.g., sudden exercise) than plants (starch, amylopectin), so the extra branching of glycogen better supports the fast glucose mobilisation animals require.

Bài tập luyện tập

Which bond type is responsible for cross-linking parallel cellulose chains into microfibrils?

(A) Peptide bonds
(B) Ionic bonds
(C) Hydrogen bonds
(D) Disulfide bonds

Lời giải chi tiết

Adjacent, parallel β-1,4-linked glucose chains in cellulose are held together by numerous **hydrogen bonds**, bundling them into microfibrils of great tensile strength. **(C)**.

Bài tập luyện tập

A student claims that all four levels of protein structure are held together by the same type of bond. Explain why this is incorrect, giving at least three different bond/interaction types involved across the four levels.

Lời giải chi tiết

This is incorrect: different levels of protein structure are stabilised by different types of bond/interaction. Primary structure is held by **peptide bonds** (covalent). Secondary structure is held by **hydrogen bonds** between backbone C=O and N–H groups. Tertiary structure is held by a mixture of **hydrogen bonds, ionic bonds** (between charged R groups), **disulfide bonds** (covalent, between cysteine R groups) and **hydrophobic interactions** (non-polar R groups clustering away from water). Quaternary structure is held together by the same range of interactions (hydrogen, ionic, hydrophobic, sometimes disulfide) but acting *between* separate polypeptide chains rather than within one chain.

Bài tập luyện tập

Which feature of collagen's structure best explains its very high tensile strength?

(A) It is a globular protein with hydrophilic R groups on its surface
(B) Three polypeptide chains wind into a triple helix, hydrogen-bonded together and cross-linked between adjacent molecules into fibrils
(C) It contains a single haem group per molecule
(D) Its primary structure contains no repeating amino acid sequence

Lời giải chi tiết

Collagen's triple helix (three chains wound together, hydrogen-bonded, with covalent cross-links between neighbouring collagen molecules forming fibrils) gives it very high resistance to stretching (tensile strength) — well suited to tendons and ligaments. **(B)**.

Bài tập luyện tập

Explain why haemoglobin, unlike collagen, is soluble in water, with reference to its tertiary structure.

Lời giải chi tiết

Haemoglobin is a globular protein: each of its four polypeptide chains folds so that hydrophilic (polar/charged) R groups face outward on the surface, in contact with the surrounding water, while hydrophobic R groups are folded into the interior, away from water. This water-facing

hydrophilic surface makes haemoglobin water-soluble — necessary for it to be carried in solution inside red blood cells. Collagen, by contrast, is a fibrous protein with a repetitive structure and R groups arranged for cross-linking and strength rather than water solubility, so it is insoluble.

Bài tập luyện tập

A mutation changes one codon in the gene for a structural protein, replacing a small, non-polar amino acid with a large, charged amino acid at a position buried in the hydrophobic core of the folded protein. Predict the most likely consequence, and explain your reasoning.

Lời giải chi tiết

This substitution is likely to **destabilise or disrupt the tertiary structure** of the protein. The original small, non-polar R group fitted into the hydrophobic (water-excluding) core of the folded protein; replacing it with a large, charged R group introduces a bulky, hydrophilic group into a region that should exclude water, disrupting the hydrophobic interactions that hold that part of the tertiary structure together and likely causing local misfolding. Because a protein's function depends on its precise 3-D shape, this misfolding could reduce or abolish the protein's normal function — illustrating how even a single amino-acid change in the primary structure can have significant structural and functional consequences.

Bài tập luyện tập

Which combination of bonds is broken when a fatty acid and glycerol are joined to form a triglyceride?

(A) Three glycosidic bonds are formed

(B) Three ester bonds are formed, releasing three water molecules

(C) One peptide bond is formed, releasing one water molecule

(D) Three hydrogen bonds are formed, requiring three water molecules

Lời giải chi tiết

Each fatty acid condenses with one of glycerol's three hydroxyl groups to form an **ester bond**, releasing one water molecule per bond — three fatty acids means three ester bonds and three water molecules released in total. **(B)**.

Bài tập luyện tập

Explain, in terms of molecular packing, why margarine made from partially hydrogenated (more saturated) vegetable oil is more solid at room temperature than the original oil.

Lời giải chi tiết

Hydrogenation reduces the number of C=C double bonds in the fatty acid tails, making the chains straighter (fewer kinks). Straighter, more saturated chains can pack together more closely and regularly, increasing the van der Waals forces between neighbouring triglyceride molecules and raising the melting point — so the partially hydrogenated fat is solid (or semi-solid) at room temperature, whereas the original, more unsaturated (kinked, loosely packed) oil is liquid.

Bài tập luyện tập

A phospholipid molecule is described as "amphipathic". What does this mean, and how does it explain bilayer formation in water?

Lời giải chi tiết

"Amphipathic" means the molecule has both a hydrophilic region (the phosphate head, which interacts favourably with water) and a hydrophobic region (the two fatty acid tails, which are repelled by water) within the same molecule. When placed in water, phospholipids spontaneously arrange so that their hydrophobic tails cluster together, shielded from water, while their hydrophilic heads face outward into the water on both sides — because this arrangement forming a bilayer minimises unfavourable contact between the hydrophobic tails and water, it is the energetically favourable (spontaneous) structure.

Bài tập luyện tập

A sample gives a positive Benedict's test directly (without any hydrolysis step). What can be concluded, and what *cannot* yet be concluded, about the sugars present?

Lời giải chi tiết

A direct positive Benedict's test shows that the sample contains at least one **reducing sugar** (a monosaccharide, or a reducing disaccharide such as maltose or lactose). It *cannot* yet be concluded whether a non-reducing sugar (such as sucrose) is also present, since a non-reducing sugar would not contribute to this positive result — a separate hydrolysis-then-Benedict's test on a fresh sample would be needed to test for that.

Bài tập luyện tập

Which test, and which observed colour change, would confirm the presence of starch rather than glycogen in a sample, given that both give a colour with iodine solution?

(A) Biuret test; purple colour confirms starch

(B) Iodine test; a distinctly blue-black colour indicates starch, while glycogen gives a red-brown colour, reflecting starch's longer unbranched helical (amylose) regions

(C) Emulsion test; a white, cloudy emulsion confirms starch

(D) DCPIP test; decolourisation confirms starch

Lời giải chi tiết

Both starch and glycogen are α-glucose polysaccharides that react with iodine, but starch's less-branched, longer helical amylose regions bind iodine molecules to give a strong **blue-black** colour, whereas glycogen's much shorter helical segments (due to heavier branching) give a weaker **red-brown** colour. **(B)**.

Bài tập luyện tập

Explain why the biuret test requires the presence of at least two peptide bonds to give a clear positive (purple) result, and predict the result for a solution of free amino acids.

Lời giải chi tiết

The purple colour of a positive biuret test arises from a coordination complex formed between Cu^{2+} ions and the nitrogen atoms of **peptide bonds**; a single peptide bond (as in a dipeptide) gives only a very weak colour, and at least two peptide bonds (as in a tripeptide or longer polypeptide) are needed for a clear, strong purple result. A solution of **free amino acids** contains no peptide bonds at all (amino acids have not yet condensed together), so it would give a **negative** (blue) result with the biuret test.

Bài tập luyện tập

A student tests an unknown white powder: iodine test — blue-black; biuret test — blue (negative); emulsion test — clear (negative). What is the powder most likely to be?

(A) A pure protein
(B) A pure lipid
(C) A pure starch sample
(D) A pure reducing sugar

Lời giải chi tiết

Blue-black with iodine indicates starch; negative biuret rules out protein; negative emulsion test rules out lipid. The powder is most consistent with **starch**. **(C)**.

Bài tập luyện tập

On a chromatogram, the solvent front moves 12.5 cm from the origin, and an unknown amino acid spot moves 9.0 cm. Calculate the R_f value.

Lời giải chi tiết

$R_f = \dfrac{9.0}{12.5} = \mathbf{0.72}$.

Bài tập luyện tập

Explain why two chromatograms of the same mixture, run using two different solvents, are likely to give different R_f values for the same substance — and why this means R_f values can only be compared when run under identical conditions.

Lời giải chi tiết

The R_f value depends on how a substance partitions between the stationary phase (paper) and the mobile phase (solvent) — a value that depends on the chemical properties of *both* the substance and the specific solvent used. A different solvent has different polarity/composition, so it will interact differently with the substance and carry it a different relative distance, changing its R_f value even though the substance itself hasn't changed. This is why an unknown R_f value can only be validly compared with known reference R_f values if both were obtained using the *same* solvent, paper and temperature.

Bài tập luyện tập

Three pigments are run on a chromatogram with a solvent front at 10.0 cm. Known reference R_f values (same solvent): chlorophyll a $= 0.65$, chlorophyll b $= 0.45$, carotene $= 0.95$. An

unknown leaf extract produces spots at 4.5 cm, 6.5 cm and 9.5 cm. Identify each spot.

Lời giải chi tiết

Calculate R_f for each spot: $R_f = \dfrac{4.5}{10.0} = 0.45$ (matches **chlorophyll b**); $R_f = \dfrac{6.5}{10.0} = 0.65$ (matches **chlorophyll a**); $R_f = \dfrac{9.5}{10.0} = 0.95$ (matches **carotene**).

Bài tập luyện tập

A student adds vitamin C solution dropwise to 2 cm^3 of DCPIP solution. It takes 1.5 cm^3 of the vitamin C solution to just decolourise the DCPIP. Using the same DCPIP volume, an orange juice sample takes only 0.5 cm^3 to decolourise it. Which sample has the higher vitamin C concentration, and by roughly what factor?

Lời giải chi tiết

A *smaller* volume needed to decolourise the same amount of DCPIP means a *higher* vitamin C concentration. The orange juice (0.5 cm^3 needed) is therefore more concentrated in vitamin C than the first solution (1.5 cm^3 needed), by a factor of $\dfrac{1.5}{0.5} = \mathbf{3}$.

Bài tập luyện tập

Explain why boiling a sucrose solution with dilute hydrochloric acid is a necessary step before it will give a positive Benedict's test.

Lời giải chi tiết

Sucrose is a non-reducing sugar and does not itself react with Benedict's reagent. Boiling with dilute HCl **hydrolyses** the glycosidic bond joining glucose and fructose, breaking sucrose down into its two constituent monosaccharides (which *are* reducing sugars). After neutralising the acid (so the following heating step does not damage the Benedict's reagent or give a false result), the now-present monosaccharides can reduce the Cu^{2+} ions in Benedict's reagent, giving the characteristic positive (brick-red) result.

Bài tập luyện tập

Which of the following amino acid R groups would you expect to be found on the *outer surface* of a water-soluble globular protein?

(A) $-CH_2CH_2CH_3$ (a non-polar hydrocarbon chain)

(B) $-CH_2COO^-$ (a charged, acidic group)

(C) $-C_6H_5$ (a non-polar aromatic ring)

(D) $-CH(CH_3)_2$ (a branched hydrocarbon group)

Lời giải chi tiết

Water-soluble globular proteins fold so that polar/charged (hydrophilic) R groups face outward into the surrounding water, while non-polar (hydrophobic) R groups cluster in the interior, away from water. Only the charged, acidic R group ($-CH_2COO^-$) is hydrophilic. **(B)**.

Bài tập luyện tập

Calculate the percentage by mass of carbon in glucose, $C_6H_{12}O_6$ (molar mass 180 g/mol; relative atomic masses C $= 12$, H $= 1$, O $= 16$).

Lời giải chi tiết

Mass of carbon per mole of glucose $= 6 \times 12 = 72$ g. Percentage by mass $= \dfrac{72}{180} \times 100 =$ **40**%.

Bài tập luyện tập

A protein loses its biological activity after being heated to 80°C, but its amino acid sequence (confirmed by later analysis) is completely unchanged. Explain this observation.

Lời giải chi tiết

Heating to 80°C has caused the protein to **denature**: the weak interactions (hydrogen bonds, ionic bonds, hydrophobic interactions, and sometimes disulfide bonds) that hold the secondary, tertiary and (if present) quaternary structure together have been disrupted, causing the protein to unfold and lose its specific 3-D shape — and with it, its biological function (e.g., an enzyme's active site is no longer correctly shaped to bind its substrate). Because denaturation does not break the strong covalent **peptide bonds** of the primary structure, the amino acid sequence itself remains completely unchanged, exactly as found on later analysis.

Bài tập luyện tập

Which of the following best explains why cellulose, but not starch, is described as a structural polysaccharide?

(A) Cellulose is made of a different monosaccharide (fructose) compared with starch (glucose)

(B) Cellulose's β-1,4-linked glucose chains run straight and are cross-linked by hydrogen bonds into strong microfibrils, whereas starch's α-1,4-linked chains coil into a compact, easily hydrolysed helix

(C) Cellulose contains nitrogen atoms, giving it extra strength

(D) Cellulose molecules are much larger than starch molecules

Lời giải chi tiết

Both are glucose polymers, but the β-1,4 linkage of cellulose produces straight chains that hydrogen-bond into strong, insoluble microfibrils (structural role), while the α-1,4 linkage of starch produces a coiled, compact, more easily hydrolysed helix (storage role). **(B)**.

Bài tập luyện tập

Explain why a solution containing only free amino acids (no peptide bonds) would give a negative result with the biuret test, but could still give a positive ninhydrin-type colour reaction (not on the syllabus in detail, but reason generally: what feature would any such test have to detect instead of a peptide bond)?

Lời giải chi tiết

The biuret test specifically detects **peptide bonds** (via the coloured complex formed between Cu^{2+} and the nitrogen atoms of the peptide backbone); free amino acids, having not yet condensed together, contain no peptide bonds and therefore give a negative biuret result. Any alternative test capable of detecting free amino acids would instead have to react with a feature common to *all* amino acids independent of peptide bonds — such as the free amino group ($-NH_2$) itself, rather than a peptide linkage.

Bài tập luyện tập

A student is given an unknown solution and told it may contain starch, a reducing sugar, protein, and/or lipid. Design a logical sequence of tests (stating the order and reason) to test for all four, using a fresh sample of the solution for each test.

Lời giải chi tiết

A sensible sequence, using a fresh sample each time: **(1) Iodine test** for starch (add iodine/KI solution directly; blue-black = positive) — quick and does not require heating, so do it first. **(2) Benedict's test** for reducing sugar (add Benedict's reagent, heat in a water bath; brick-red precipitate = positive). **(3) Biuret test** for protein (add NaOH then dilute $CuSO_4$; purple = positive). **(4) Emulsion test** for lipid (shake with ethanol, then pour into water; cloudy white = positive). Each test uses a separate fresh sample so that reagents from one test do not interfere with the results of another; if a negative Benedict's result is obtained, a further hydrolysis step (boil with dilute HCl, neutralise, then repeat Benedict's) could be carried out on another fresh sample to check for a non-reducing sugar such as sucrose.

Bài tập luyện tập

Which structural feature of an unsaturated fatty acid directly causes it to have a lower melting point than a saturated fatty acid of the same chain length?

(A) It has fewer carbon atoms

(B) Its carboxyl group is more polar

(C) Its C=C double bond(s) create a kink that prevents tightly-packed, ordered chains

(D) It contains a phosphate group

Lời giải chi tiết

Each C=C double bond in an unsaturated fatty acid introduces a rigid kink in the hydrocarbon chain, preventing neighbouring molecules from packing closely and regularly; the resulting weaker intermolecular (van der Waals) forces lower the melting point compared with a straight, saturated chain of the same length. **(C)**.

Bài tập luyện tập

Explain why testing a solution for lipid using the emulsion test does *not* require heating, unlike the Benedict's test.

Lời giải chi tiết

The emulsion test relies on a simple physical/solubility principle: lipids dissolve readily in ethanol but are insoluble in water, so when the ethanol–lipid solution is poured into water, the

lipid comes out of solution as fine droplets that scatter light, producing a visible white emulsion — no chemical reaction (and therefore no heat-driven reaction) is required. Benedict's test, by contrast, relies on a genuine chemical **redox reaction** (the reducing sugar reduces blue Cu^{2+} ions to a brick-red precipitate of Cu_2O), which requires heating to proceed at a useful rate.

Bài tập luyện tập

A researcher compares the water potential effect of storing glucose directly versus storing the same mass of glucose units polymerised into glycogen inside a liver cell. Explain the advantage of storing glucose as glycogen rather than as free glucose.

Lời giải chi tiết

Free glucose molecules in solution are individually osmotically active, each contributing to lowering the cell's water potential — storing a large quantity of free glucose would draw a large amount of water into the cell by osmosis, risking swelling and even bursting. Glycogen, however, is a single large, compact, branched, and relatively insoluble molecule: bundling many thousands of glucose units into one glycogen molecule means far fewer individual osmotically-active particles are present for the same total mass of stored glucose, so glycogen storage has a much smaller effect on the cell's water potential than storing the equivalent amount of glucose in free (unpolymerised) form.

Enzymes

AS Level

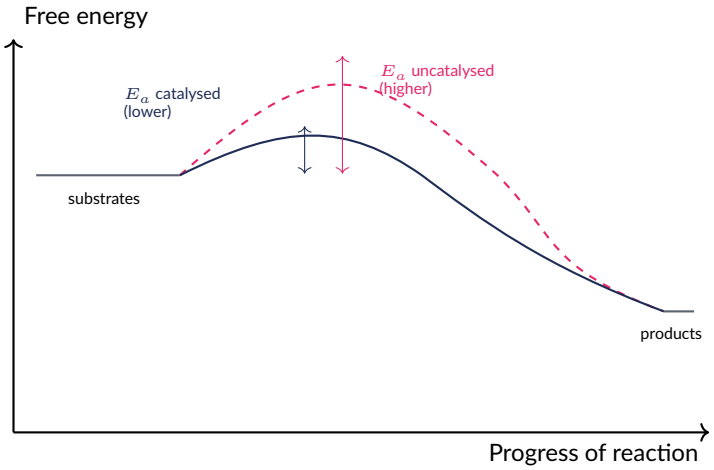
Mục tiêu Unit: Enzyme là chất xúc tác sinh học bản chất protein; năng lượng hoạt hóa và mô hình ổ khóa–chìa khóa so với cảm ứng khớp (induced fit); ảnh hưởng của nhiệt độ, pH, nồng độ cơ chất và nồng độ enzyme lên tốc độ phản ứng; tính toán tốc độ phản ứng ban đầu từ số liệu thực nghiệm; chất ức chế cạnh tranh, không cạnh tranh và ức chế ngược (feedback) trong điều hòa chuyển hóa; enzyme cố định (immobilised enzyme) và ứng dụng công nghiệp.

3.1 Enzymes as Biological Catalysts

3.1.1 Globular proteins and activation energy

An **enzyme** is a globular protein that acts as a biological **catalyst**: it speeds up the rate of a specific biochemical reaction without being used up or permanently changed itself, and without altering the equilibrium position or the overall energy change of the reaction. Enzymes are highly folded, water-soluble proteins whose precise three-dimensional (tertiary and, for many, quaternary) structure creates a pocket called the **active site**.

For a reaction to proceed, reactant (substrate) molecules must first absorb enough energy to reach an unstable, high-energy **transition state** before they can be converted to products. The minimum energy required to reach this transition state is the **activation energy** (E_a). Enzymes speed up reactions by providing an alternative reaction pathway with a **lower activation energy**, so that a far greater proportion of substrate molecules already possess enough energy to react at a given temperature.



Reaction progress diagram: the enzyme-catalysed pathway (solid navy curve) has a lower activation energy peak than the uncatalysed pathway (dashed pink curve), so a larger fraction of substrate molecules can cross the energy barrier at a given temperature. The overall free-energy change (start to end level) is identical in both cases – the enzyme changes only the rate, not the thermodynamics, of the reaction.

Khái niệm cốt lõi

An enzyme lowers E_a by binding the substrate(s) in a way that strains particular bonds, brings reacting groups into the correct orientation, and (for reactions between two substrates) holds them close together – all of which make the transition state easier to reach. Because the enzyme itself is regenerated unchanged at the end of the reaction, a small quantity of enzyme can catalyse the conversion of a very large number of substrate molecules.

VN **GIẢI THÍCH TIẾNG VIỆT**

Enzyme là protein hình cầu đóng vai trò **chất xúc tác sinh học**: làm tăng tốc độ phản ứng mà không bị biến đổi hay mất đi, và không làm thay đổi vị trí cân bằng hay mức năng lượng tổng của phản ứng. Enzyme hoạt động bằng cách hạ thấp **năng lượng hoạt hóa** (E_a) – mức năng lượng tối thiểu cần thiết để cơ chất đạt trạng thái chuyển tiếp – nhờ đó nhiều phân tử cơ chất hơn có đủ năng lượng để phản ứng ở cùng một nhiệt độ. Vì enzyme được tái sinh nguyên vẹn sau phản ứng nên một lượng nhỏ enzyme có thể xúc tác rất nhiều phân tử cơ chất.

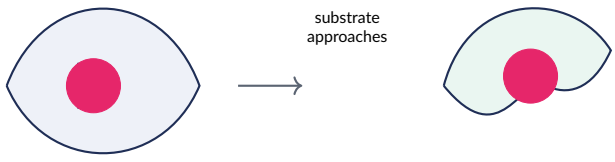
3.1.2 The active site: specificity, lock-and-key and induced fit

The **active site** is a pocket or cleft on the enzyme's surface, formed by the folding of the polypeptide chain(s), whose shape and the chemical properties of its lining (R groups that can form hydrogen bonds, ionic bonds, or hydrophobic interactions) are complementary to one particular substrate (or a small group of closely related substrates). This complementarity is the basis of enzyme **specificity** – each enzyme catalyses essentially only one reaction (or one type of reaction).

Two models describe how the substrate binds the active site to form an **enzyme–substrate complex**:

Feature	Lock-and-key model	Induced-fit model
Active site shape	Rigid; fixed shape exactly matching the substrate, like a key fitting a lock	Flexible; initially only roughly complementary
What happens on binding	Substrate simply slots into a pre-formed shape	Active site *changes shape slightly* as substrate binds, moulding tightly around it
Effect on substrate	Substrate is unaffected structurally	Substrate's bonds are **strained/distorted**, lowering E_a further
Accuracy	Oversimplified; does not explain why some substrate analogues bind poorly, or how enzymes strain bonds	Currently accepted model – supported by X-ray/structural evidence that active-site shape changes on substrate binding

Comparison of the lock-and-key and induced-fit models of enzyme–substrate binding.



(a) free enzyme – active site not yet moulded (b) enzyme–substrate complex – active site moulds around substrate, straining its bonds

Induced fit: the active site (navy outline) is not a rigid pocket – it flexes and tightens around the substrate (pink) on binding, distorting the substrate's bonds and helping to lower the activation energy of the reaction.

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Mô hình **cảm ứng khớp (induced fit)** chính xác hơn mô hình **ổ khóa–chìa khóa**: trung tâm hoạt động (active site) của enzyme **không cứng nhắc** mà thay đổi hình dạng nhẹ khi cơ chất gắn vào, ôm khít lấy cơ chất để tạo phức hợp enzyme–cơ chất (enzyme–substrate complex), đồng thời **làm căng/biến dạng các liên kết của cơ chất**, giúp giảm thêm năng lượng hoạt hóa cần cho phản ứng. Tính đặc hiệu (specificity) của enzyme bắt nguồn từ sự bổ sung về hình dạng và tính chất hóa học giữa trung tâm hoạt động và cơ chất.

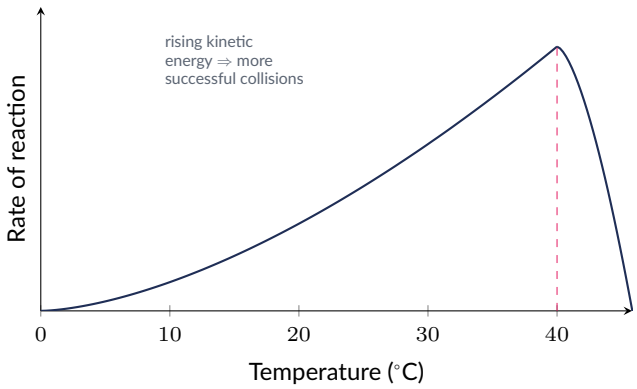
Specificity means one enzyme normally catalyses only one reaction (or a narrow group of closely related reactions), because only substrates with the correct shape and chemical groups can bind productively in the active site and form the transition state.

3.2 Factors Affecting the Rate of Enzyme-Catalysed Reactions

3.2.1 Temperature

Raising the temperature increases the **kinetic energy** of both enzyme and substrate molecules. Molecules move faster and collide more often, and a greater proportion of collisions have enough energy to exceed the activation energy – so the rate of reaction **increases with temperature**, up to an **optimum temperature** (often around $37\,^{\circ}$C for human enzymes, though it varies between organisms and enzymes).

Beyond the optimum, rate falls sharply because heat energy disrupts the weak, non-covalent bonds (**hydrogen bonds** and **ionic bonds**) that maintain the enzyme's precise tertiary structure. As these bonds break, the polypeptide chain vibrates more violently and unfolds, distorting and eventually destroying the shape of the active site – the enzyme is **denatured**. Denaturation does *not* break the strong covalent peptide bonds of the primary structure (the polypeptide backbone remains intact); it destroys only the tertiary/quaternary folding that gave the active site its specific shape. Once denatured, the enzyme can no longer bind its substrate effectively and activity is permanently lost (denaturation by heat is generally irreversible).



Rate of reaction against temperature. Below the optimum, rate rises because of increasing kinetic energy and collision frequency. Above the optimum, an increasing proportion of enzyme molecules are denatured, so rate falls steeply and eventually reaches zero.

(!) Lỗi thường gặp: Đừng viết rằng nhiệt độ cao "phá vỡ liên kết peptide" hay "phá hủy cấu trúc bậc 1" của enzyme – **sai**. Nhiệt chỉ phá vỡ các liên kết **yếu** (liên kết hydro, liên kết ion) duy trì cấu trúc bậc ba/bậc bốn, làm enzyme **biến tính (denature)** và mất hình dạng trung tâm hoạt động; mạch polypeptide (cấu trúc bậc 1, các liên kết peptide) vẫn nguyên vẹn.

Ví dụ mẫu · Q_{10} and predicting rate change

An enzyme reaction has a rate of 4.0 cm^3 O_2 per minute at $20\,^\circ$C. Over the temperature range well below its optimum, the rate approximately doubles for every $10\,^\circ$C rise (a Q_{10} of 2). Predict the rate at $40\,^\circ$C.

Reasoning: $40\,^\circ$C is $20\,^\circ$C above $20\,^\circ$C, i.e. two $10\,^\circ$C steps.
Rate at $30\,^\circ$C$= 4.0 \times 2 = 8.0$ cm^3/min.
Rate at $40\,^\circ$C$= 8.0 \times 2 =$ **16.0** cm^3/min (provided $40\,^\circ$C does not exceed the enzyme's optimum – if it does, the actual rate would be lower than this prediction because denaturation would already be reducing the number of active enzyme molecules).

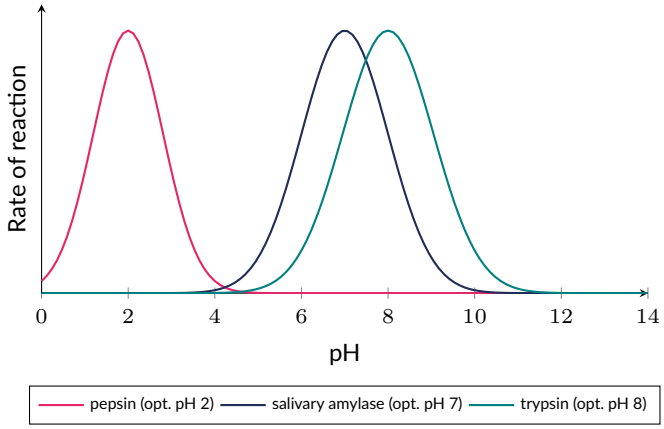
VN **GIẢI THÍCH TIẾNG VIỆT**

Q_{10} là hệ số thể hiện tốc độ phản ứng tăng bao nhiêu lần khi nhiệt độ tăng thêm $10\,^\circ$C (thường $Q_{10} \approx 2$ với phản ứng enzyme, khi còn dưới nhiệt độ tối ưu). Lưu ý: quy luật này **chỉ đúng dưới nhiệt độ tối ưu**; vượt qua nhiệt độ tối ưu, enzyme bắt đầu biến tính nên tốc độ thực tế sẽ thấp hơn nhiều so với dự đoán theo Q_{10}.

3.2.2 pH

Each enzyme has an **optimum pH** at which its rate of reaction is greatest. Away from this optimum, changes in H^+ concentration alter the charges on ionisable R groups (e.g. $-$COOH/$-$COO$^-$, $-NH_2$/$-NH_3^+$) in and around the active site. This disrupts the ionic and hydrogen bonds that hold the tertiary structure in its correct shape, gradually changing (and, at extremes of pH, permanently denaturing) the active site so the enzyme–substrate complex can no longer form efficiently.

Different enzymes have very different optimum pH values, matched to the environment in which they normally work:



Rate against pH for three digestive enzymes. Pepsin (stomach) has a low optimum (≈pH 2), matching the highly acidic gastric juice; salivary amylase works best near neutral pH (≈7); trypsin (small intestine) has a higher optimum (≈pH 8), matching the alkaline environment created by bicarbonate secretions.

Ví dụ mẫu · Predicting the effect of a pH change

Trypsin (optimum pH 8) is moved from the duodenum (pH 8) into a solution buffered at pH 2. Predict and explain the effect on its rate of reaction.

At pH 2, the concentration of H^+ is far higher than at trypsin's optimum. This changes the charge on ionisable R groups in and around the active site, disrupting the ionic and hydrogen bonds that hold trypsin's tertiary structure in shape. The active site shape is lost – trypsin is

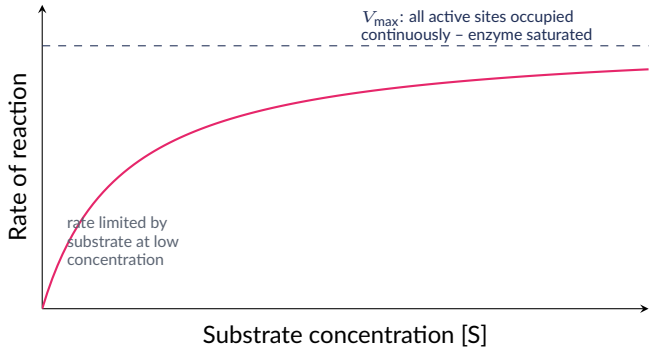
denatured at this extreme pH – so its rate of reaction falls to (approximately) **zero**, and does not recover even if the enzyme is later returned to pH 8.

VN **GIẢI THÍCH TIẾNG VIỆT**

pH tác động theo cơ chế tương tự nhiệt độ nhưng qua **điện tích** của các nhóm R (R group) trên chuỗi polypeptide: pH lệch khỏi giá trị tối ưu làm thay đổi điện tích các nhóm này, phá vỡ liên kết ion/hydro giữ cấu trúc bậc ba, từ đó làm biến dạng (và ở pH cực đoan, làm biến tính) trung tâm hoạt động. Mỗi enzyme có pH tối ưu khớp với môi trường hoạt động của nó: pepsin (dạ dày) ≈ pH 2; trypsin (ruột non) ≈ pH 8; amylase nước bọt ≈ pH 7.

3.2.3 Substrate concentration

At a fixed enzyme concentration, increasing substrate concentration increases the rate of reaction because there are more substrate molecules available to collide with, and bind to, the (limited number of) active sites present. As substrate concentration continues to rise, an increasing proportion of active sites are occupied at any instant, and the rate of increase slows. Eventually, at high substrate concentration, **every** active site is occupied continuously – the enzyme is **saturated** – and the rate reaches a constant **maximum rate**, V_{max}. Adding still more substrate beyond this point has no further effect on rate, because rate is now limited purely by the fixed number of enzyme molecules (and how quickly each active site can process substrate and release product), not by substrate availability.



Rate of reaction against substrate concentration at a fixed enzyme concentration: an initial near-linear rise (rate limited by collision frequency) that curves and plateaus at V_{max} once every active site is continuously occupied.

Ví dụ mẫu · Reading V_{max} from a graph

In an experiment, rate of reaction is measured at increasing substrate concentrations; above $[S] = 8$ mM the rate no longer increases and stays constant at $12\,cm^3O_2$/min even when $[S]$ is doubled again. Explain this observation and name the value $12\,cm^3$/min.

Beyond $[S] = 8$ mM, every active site of every enzyme molecule present is already occupied at all times – the enzyme is saturated. Because there is now a fixed number of active sites processing substrate at their maximum possible turnover rate, adding more substrate cannot increase the rate further. $12\,cm^3$/min is the **maximum rate**, V_{max}, for this fixed enzyme concentration.

3.2.4 Enzyme concentration

Provided substrate is in **excess** (never limiting) and other conditions (temperature, pH) are constant, rate of reaction is **directly proportional** to enzyme concentration: doubling the number of enzyme molecules doubles the number of active sites available at any instant, so the initial rate doubles.

Ví dụ mẫu · Enzyme concentration and rate

At a fixed, saturating substrate concentration, an enzyme concentration of $2\,\text{mg/cm}^3$ produces an initial rate of $5.0\,\text{cm}^3\text{O}_2$/min. Predict the initial rate if enzyme concentration is raised to $6\,\text{mg/cm}^3$, all else unchanged.

Since substrate remains in excess, rate $\propto$ enzyme concentration. Enzyme concentration has tripled ($2 \to 6\,\text{mg/cm}^3$), so rate should also triple: $5.0 \times 3 = \mathbf{15.0}\ \text{cm}^3/\text{min}$.

Rate $\propto$ [enzyme] only while substrate is **non-limiting** (in excess). If substrate concentration is also low, doubling enzyme concentration will not necessarily double the rate, because active sites may compete for a limited pool of substrate.

3.3 Measuring and Calculating Rates of Reaction

3.3.1 Initial rate and the tangent-at-origin method

Enzyme reactions are commonly followed by measuring the volume of a gas produced (e.g. O_2 from catalase decomposing hydrogen peroxide), a change in mass, or a change in absorbance/colour, plotted against time. As substrate is used up, the rate of reaction **decreases** over the course of the reaction (the graph of volume/absorbance against time curves and flattens as it approaches a plateau). To compare different conditions fairly (same starting substrate concentration in every case), biologists use the **initial rate of reaction** – the rate at time $t = 0$, before any substrate has been used up.

The initial rate is found by drawing a **tangent to the curve at the origin** ($t = 0$) and calculating its gradient:

$$\text{initial rate} = \frac{\text{change in volume (or mass, or absorbance)}}{\text{change in time}} = \frac{\Delta y}{\Delta t}$$

using two points read directly off the tangent line (not off the curve itself, since the curve's own gradient changes continuously).

Ví dụ mẫu · Calculating initial rate from a tangent

A tangent drawn to a volume–time curve at the origin passes through the points $(0\,\text{s},\ 0\,\text{cm}^3)$ and $(25\,\text{s},\ 20\,\text{cm}^3)$. Calculate the initial rate of reaction, in cm^3/s and in cm^3/min.

$$\text{initial rate} = \frac{\Delta y}{\Delta t} = \frac{20 - 0\ \text{cm}^3}{25 - 0\ \text{s}} = \mathbf{0.80}\ \text{cm}^3/\text{s}$$

Converting to per minute: $0.80 \times 60 = \mathbf{48}\ \text{cm}^3/\text{min}$.

Ví dụ mẫu · Catalase and hydrogen peroxide

Catalase decomposes hydrogen peroxide: $2\,\text{H2O2} \to 2\,\text{H2O} + \text{O2}$. In the first 60 seconds of a reaction, $24\,\text{cm}^3$ of oxygen gas is collected. Calculate the initial rate of reaction, assuming the volume–time graph is approximately linear over this interval.

$$\text{rate} = \frac{\text{volume}}{\text{time}} = \frac{24\ \text{cm}^3}{60\ \text{s}} = \mathbf{0.40}\ \text{cm}^3/\text{s}$$

Ví dụ mẫu · Unit conversion

Catalase produces $18\,\text{cm}^3$ of O_2 in the first 45 seconds of a reaction. Express the initial rate in cm^3/min.

Rate $= \dfrac{18\ \text{cm}^3}{45\ \text{s}} = 0.40\ \text{cm}^3/\text{s}$. Converting: $0.40 \times 60 =$ **24 cm^3**/min.

(!) Lỗi thường gặp: Học sinh hay tính "tốc độ" bằng cách lấy thể tích cuối cùng (khi phản ứng đã dừng, cơ chất cạn kiệt) chia cho tổng thời gian – đây **không phải** tốc độ ban đầu. Tốc độ ban đầu (initial rate) phải được xác định từ **độ dốc của tiếp tuyến tại gốc tọa độ** ($t = 0$), vì tốc độ phản ứng enzyme giảm dần theo thời gian khi cơ chất bị tiêu hao.

3.4 Enzyme Inhibition and Metabolic Regulation

3.4.1 Competitive inhibitors

A **competitive inhibitor** is a molecule structurally similar to the normal substrate. It binds **reversibly to the active site itself**, physically blocking the substrate from binding, but does not react. Because it competes directly with substrate for the same active site, its inhibitory effect can be reduced (largely overcome) by substantially **increasing substrate concentration**: with enough substrate molecules present, they out-compete the inhibitor for access to the (unaffected) active sites, so V_{max} can still eventually be reached, just at a higher substrate concentration than without the inhibitor.

3.4.2 Non-competitive inhibitors

A **non-competitive inhibitor** binds **reversibly (or sometimes irreversibly) to a site other than the active site** – an **allosteric site**. Binding here changes the overall tertiary structure of the enzyme, which distorts the shape of the active site elsewhere on the molecule, even though the inhibitor never occupies the active site directly. Because the inhibitor does not compete with substrate for the active site, increasing substrate concentration **cannot** restore full activity to the affected enzyme molecules – V_{max} is permanently **reduced** for as long as the inhibitor remains bound.

Feature	Competitive inhibitor	Non-competitive inhibitor
Binding site	Active site (structurally resembles substrate)	Allosteric site (separate from active site)
Effect on active site	Physically blocks it; active site itself unchanged	Distorts active site shape indirectly
Effect of excess substrate	Largely overcome – substrate out-competes inhibitor	**Not** overcome – inhibitor does not compete for the active site
Effect on V_{max}	Unchanged (same maximum reachable, at higher $[S]$)	**Reduced** (affected enzyme molecules cannot reach normal turnover)
Effect on rate at low $[S]$	Reduced	Reduced

Comparing competitive and non-competitive inhibition.

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Chất ức chế **cạnh tranh (competitive)** có cấu trúc giống cơ chất, gắn thuận nghịch **ngay tại trung tâm hoạt động**, nên tăng nồng độ cơ chất có thể "lấn át" và khắc phục được phần lớn tác dụng ức chế (V_{max} không đổi). Chất ức chế **không cạnh tranh (non-competitive)** gắn vào một vị trí khác gọi là **vị trí dị lập thể (allosteric site)**, làm biến dạng gián tiếp trung tâm hoạt động ở nơi khác trên phân tử – vì không cạnh tranh trực tiếp với cơ chất nên **tăng nồng độ cơ chất**

không khắc phục được, và V_{max} bị **giảm** vĩnh viễn khi còn chất ức chế gắn vào.

Ví dụ mẫu · Distinguishing inhibitor type from data

An enzyme's rate of reaction is measured at several substrate concentrations, with and without a fixed concentration of an unknown inhibitor:

$[S]$ (mM)	Rate, no inhibitor (units)	Rate, with inhibitor (units)
2	20	8
6	44	22
20	60	52
50	60	60

Identify the type of inhibitor and justify your answer.

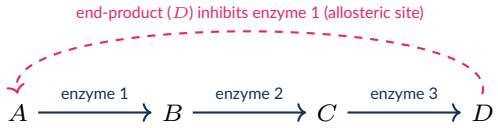
Reasoning: at low $[S]$ the inhibitor clearly reduces rate (8 vs 20; 22 vs 44). However, at high $[S] = 50$ mM, the rate *with* inhibitor (60) becomes **equal** to the rate without inhibitor (60) – i.e. the same V_{max} is eventually reached once substrate is in large excess. This is the signature of a **competitive inhibitor**: it can be out-competed by a sufficiently high substrate concentration, so V_{max} is unaffected, only reached at a higher $[S]$.

3.4.3 End-product inhibition: regulation of metabolic pathways

Many metabolic pathways consist of a sequence of enzyme-catalysed steps, each producing the substrate for the next enzyme:

$$A \xrightarrow{\text{enzyme 1}} B \xrightarrow{\text{enzyme 2}} C \xrightarrow{\text{enzyme 3}} D \text{ (end product)}$$

In **end-product inhibition** (a form of **negative feedback**), the final product (D) of the pathway acts as a **non-competitive (allosteric) inhibitor** of an earlier enzyme in the sequence (commonly the first committed step, enzyme 1). When D accumulates, it binds the allosteric site of enzyme 1 and inhibits it, slowing production of B and hence of C and D itself. As D is used up elsewhere in the cell and its concentration falls, less of it is available to inhibit enzyme 1, so the pathway speeds up again. This self-limiting loop keeps the concentration of the end product within a narrow, appropriate range without wasting resources over-producing it.



End-product inhibition: accumulation of the final product D allosterically (non-competitively) inhibits the first enzyme of its own pathway, a negative-feedback loop that prevents overproduction.

Ví dụ mẫu · End-product inhibition in amino acid synthesis

In bacteria, the amino acid isoleucine is synthesised from threonine through a five-step enzyme pathway. When isoleucine concentration in the cell rises, it binds an allosteric site on the *first* enzyme of the pathway (threonine deaminase), inhibiting it. Explain why this is efficient for the cell, and why the inhibition targets the *first* enzyme rather than the last.

Inhibiting the *first* enzyme immediately halts the whole pathway at its earliest step, preventing the cell from wasting energy and raw materials (threonine and other intermediates) synthesising a partial pathway of intermediate compounds (B, C, ...) that would otherwise accumulate

uselessly if only the last step were blocked. As isoleucine is consumed (e.g. in protein synthesis) and its concentration falls, inhibition is relieved and the pathway resumes – keeping isoleucine concentration in a narrow, metabolically appropriate range.

VN **GIẢI THÍCH TIẾNG VIỆT**

Ức chế ngược (end-product inhibition) là một dạng **phản hồi âm (negative feedback)**: sản phẩm cuối cùng của một chuỗi phản ứng enzyme quay lại ức chế enzyme đầu tiên (thường tại vị trí dị lập thể, tức ức chế không cạnh tranh). Khi sản phẩm cuối tích lũy nhiều, tốc độ tổng hợp giảm; khi sản phẩm cuối bị tiêu thụ bớt, ức chế giảm và con đường chuyển hóa lại tăng tốc – giữ nồng độ sản phẩm ổn định trong giới hạn phù hợp mà không lãng phí nguyên liệu.

3.5 Immobilised Enzymes

An **immobilised enzyme** is one that has been physically attached to, or trapped within, an inert (non-reactive) support material, so that it is not free to move within the reaction mixture. Immobilisation is central to using enzymes economically at industrial scale.

Method	Description	Notes
Adsorption	Enzyme binds to the surface of an inert material (e.g. glass beads, resin) via weak ionic/hydrophobic bonds	Cheap, simple; enzyme can leach off if bonds are weak
Entrapment	Enzyme trapped within a porous matrix, e.g. **alginate beads** or gel, that lets small substrate/product molecules diffuse in/out but retains the (larger) enzyme	Very widely used (e.g. lactase in alginate beads); enzyme not chemically altered so activity is largely retained
Covalent bonding	Enzyme chemically (covalently) bonded to an inert support (e.g. cellulose, resin beads)	Very secure, low leaching; risk of distorting active site during bonding, reducing activity
Membrane/capsule separation	Enzyme kept behind a partially permeable membrane, or within a microcapsule, that allows small substrate/product molecules through but not the enzyme	Enzyme never directly contacts the bulk reaction mixture; easy separation

The four main methods of enzyme immobilisation used industrially.

Advantages of immobilisation: (1) the enzyme is easily **separated** from the product (simply remove/filter the beads or support), giving a purer product and avoiding contamination of food/pharmaceutical products with enzyme; (2) the enzyme can be **reused** many times, reducing cost; (3) immobilised enzymes are often **more thermally stable** than free enzyme in solution (the support restricts unfolding), allowing reactions to run at slightly higher temperatures without denaturation; (4) immobilisation enables **continuous-flow processing** (substrate solution is passed continuously over/through a packed column of immobilised enzyme), rather than the batch process needed with free enzyme, greatly increasing throughput.

Ví dụ mẫu · Lactase immobilised in alginate beads

Lactase (the enzyme that hydrolyses lactose to glucose and galactose) is immobilised by **entrapment in alginate beads** and packed into a column. Milk is passed continuously through the column to produce lactose-free milk for lactose-intolerant consumers. Explain (i) why en-

trapment (rather than free enzyme in solution) is used, and (ii) why the beads must be porous enough to let lactose and its products through but not the enzyme.

(i) Entrapment lets the milk (and its dissolved lactose) flow continuously past the immobilised lactase without the enzyme ending up dissolved *in* the milk itself – the lactase can be reused for many batches (reducing cost) and the final product contains no enzyme protein that would need to be removed, and the beads' matrix also gives the enzyme some protection against denaturation.

(ii) The alginate matrix must have pores small enough to retain the (relatively large) lactase enzyme molecules within the bead, but large enough to allow the much smaller lactose molecule to diffuse *in* to reach the active sites, and glucose and galactose to diffuse *out* into the milk – otherwise the reaction could not occur, or the products could not be recovered.

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Enzyme cố định (immobilised enzyme) được gắn/giữ trên hoặc trong một chất mang trơ, ví dụ enzyme lactase bị **bẫy (entrapment) trong hạt alginate**, dùng để sản xuất sữa không lactose. Lợi ích chính: enzyme có thể **tái sử dụng nhiều lần**, **dễ tách khỏi sản phẩm** (chỉ cần lọc bỏ hạt), thường **bền nhiệt hơn**, và cho phép **vận hành liên tục** (dòng chảy substrate liên tục qua cột chứa enzyme) thay vì phải làm theo từng mẻ (batch) như enzyme tự do.

Ví dụ mẫu · Continuous-flow advantage, numerically

A batch reactor using free lactase processes $500\,\text{dm}^3$ of milk per 8-hour batch, requiring 1 hour of downtime between batches to add fresh enzyme (enzyme is discarded with the product). An immobilised-enzyme column processes milk continuously at the same rate, with only 2 hours downtime per week for cleaning. Compare the volume of milk processed by each system over one 7-day week (assume continuous 24-hour operation is attempted in both cases).

Batch system: each cycle takes $8 + 1 = 9$ hours. Number of cycles per week $= \dfrac{7 \times 24}{9} = \dfrac{168}{9} \approx 18.7 \to 18$ complete cycles. Volume $= 18 \times 500 = 9000\,\text{dm}^3$.

Immobilised column: operates continuously at $\dfrac{500\ \text{dm}^3}{8\ \text{h}} = 62.5\,\text{dm}^3/\text{h}$ for $168 - 2 = 166$ hours. Volume $= 62.5 \times 166 = 10\,375\,\text{dm}^3$.

The immobilised system processes about $1375\,\text{dm}^3$ (roughly 15%) more milk in the same week, purely because it avoids repeated batch downtime and enzyme replacement – illustrating the throughput advantage of continuous-flow processing with a reusable, immobilised enzyme.

(!) Lỗi thường gặp: Đừng viết chung chung "enzyme cố định tốt hơn enzyme tự do" mà không nêu rõ **vì sao** – đề thi luôn yêu cầu giải thích cụ thể: tái sử dụng được (giảm chi phí), dễ tách sản phẩm (sản phẩm tinh khiết hơn, không lẫn enzyme), bền nhiệt hơn (chất mang hạn chế biến tính), và cho phép vận hành liên tục (continuous process) thay vì phải dừng lại theo từng mẻ.

Ôn tập nhanh: Enzyme = protein hình cầu, xúc tác sinh học, hạ E_a. Cảm ứng khớp (induced fit) > ổ khóa–chìa khóa (lock-and-key). Nhiệt độ/pH: tăng tốc độ đến điểm tối ưu, sau đó biến tính (đứt liên kết H/ion, không đứt liên kết peptide). $[S]$: tốc độ tăng rồi bão hòa tại V_{max}. $[E]$ (khi cơ chất dư thừa): tốc độ tỉ lệ thuận. Tốc độ ban đầu = độ dốc tiếp tuyến tại gốc tọa độ. Ức chế cạnh tranh: gắn active site, khắc phục được bằng dư cơ chất, V_{max} không đổi. Ức chế không cạnh tranh: gắn allosteric site, không khắc phục được, V_{max} giảm. Ức chế ngược: sản phẩm cuối ức chế enzyme đầu tiên trong chuỗi chuyển hóa. Enzyme cố định: tái sử dụng, dễ tách sản phẩm, bền nhiệt hơn, vận hành liên tục.

3.6 Practice Questions

Bài tập luyện tập

Which statement best explains why enzymes increase the rate of a reaction?

(A) They increase the overall energy released by the reaction

(B) They provide an alternative pathway with a lower activation energy, so more substrate molecules can react at a given temperature

(C) They raise the temperature of the reaction mixture

(D) They are permanently consumed in the reaction, shifting the equilibrium

Lời giải chi tiết

Enzymes do not change the total energy released (thermodynamics) or the equilibrium position; they lower the activation energy required, so a larger proportion of substrate molecules already have enough kinetic energy to react at a given temperature. **(B)**.

Bài tập luyện tập

Explain, in terms of energy, why a small amount of enzyme can catalyse the conversion of a very large amount of substrate over time.

Lời giải chi tiết

The enzyme is not used up or permanently altered by the reaction – it lowers the activation energy of the reaction, forms an enzyme–substrate complex, converts substrate to product, and is released **unchanged and reusable**. The same enzyme molecule can therefore repeatedly bind new substrate molecules and catalyse the reaction again and again, so a small quantity of enzyme is sufficient to process a much larger quantity of substrate.

Bài tập luyện tập

Which feature of the induced-fit model is *not* part of the lock-and-key model?

(A) The active site is specific to a particular substrate

(B) The active site changes shape slightly as the substrate binds, straining the substrate's bonds

(C) An enzyme–substrate complex forms

(D) The enzyme is a globular protein

Lời giải chi tiết

Both models agree the active site is specific and forms an enzyme–substrate complex, and that enzymes are globular proteins. Only the induced-fit model adds that the active site is flexible and changes shape (moulding around the substrate and straining its bonds) rather than being a rigid pre-formed shape. **(B)**.

Bài tập luyện tập

An enzyme reaction is run at $50\,^{\circ}$C, well above the enzyme's optimum of $37\,^{\circ}$C, then substrate concentration is doubled. What happens to the rate?

(A) Rate roughly doubles, since substrate concentration always determines rate

(B) Rate stays very low, because the enzyme is already denatured and no amount of substrate can restore its active site shape

(C) Rate becomes exactly zero

(D) Rate increases fourfold

Lời giải chi tiết

At $50\,^{\circ}$C, hydrogen and ionic bonds maintaining tertiary structure have already broken – the active site's shape is permanently lost (denatured). Since the enzyme–substrate complex can no longer form properly, adding more substrate cannot restore activity. **(B)**.

Bài tập luyện tập

State precisely which type of bond is broken during heat denaturation of an enzyme, and which is *not* broken.

Lời giải chi tiết

Heat breaks the weak **hydrogen bonds and ionic bonds** that maintain the enzyme's tertiary (and quaternary, if present) structure, causing the polypeptide to unfold and the active site to lose its shape. Heat does *not* break the strong covalent **peptide bonds** of the primary structure – the polypeptide chain's sequence of amino acids remains intact even after denaturation.

Bài tập luyện tập

An enzyme has a rate of $6.0\,\text{cm}^3$/min at $15\,^{\circ}$C and a Q_{10} of 2 over the range studied (well below its optimum). Calculate the expected rate at $35\,^{\circ}$C.

(A) $12\,\text{cm}^3$/min

(B) $24\,\text{cm}^3$/min

(C) $48\,\text{cm}^3$/min

(D) $18\,\text{cm}^3$/min

Lời giải chi tiết

$35 - 15 = 20\,^{\circ}$C rise = two $10\,^{\circ}$C steps. Rate doubles twice: $6.0 \times 2 \times 2 =$ **24** cm^3/min. **(B)**.

Bài tập luyện tập

Pepsin (optimum pH 2) is tested at pH 7. Predict and explain the effect on its rate of reaction.

Lời giải chi tiết

At pH 7, far above pepsin's optimum of pH 2, the much lower H^+ concentration alters the charge on ionisable R groups in and around pepsin's active site. This disrupts the ionic and hydrogen bonds maintaining its tertiary structure, distorting (and, this far from the optimum, likely denaturing) the active site. Pepsin's rate of reaction at pH 7 would therefore be very low or effectively zero.

Bài tập luyện tập

Which enzyme would you expect to have the highest optimum pH?

(A) Pepsin

(B) Salivary amylase

(C) Trypsin

(D) All digestive enzymes share the same optimum pH

Lời giải chi tiết

Trypsin acts in the small intestine, which is maintained slightly alkaline (around pH 8) by bicarbonate secretions, so trypsin's optimum (≈pH 8) is higher than pepsin's (≈pH 2, matching acidic gastric juice) or salivary amylase's (≈pH 7). **(C)**.

Bài tập luyện tập

Explain why the rate–pH curve for an enzyme is typically a bell shape (rising then falling) rather than rate simply increasing indefinitely with pH.

Lời giải chi tiết

Moving *toward* the optimum pH from either side improves the charge distribution/ionic and hydrogen bonding needed to maintain the correct active-site shape, so rate rises. Moving *beyond* the optimum in either direction (too acidic or too alkaline) disrupts these bonds and distorts (or denatures) the active site, so rate falls again on both sides – giving a symmetric-ish peak (bell shape) rather than a curve that keeps rising.

Bài tập luyện tập

At a fixed enzyme concentration, rate of reaction is measured at increasing substrate concentrations and plotted. Above $[S] = 10\,\text{mM}$ the rate stays constant even when $[S]$ is tripled. Explain this observation.

Lời giải chi tiết

Beyond $[S] = 10\,\text{mM}$, every active site of every enzyme molecule present is continuously occupied – the enzyme is **saturated**. Since the fixed number of enzyme molecules (and their fixed maximum turnover rate) is now the limiting factor, not substrate availability, adding more substrate cannot increase the rate further; the rate has reached its maximum, V_{max}.

Bài tập luyện tập

Which graph feature would you expect if enzyme concentration is doubled while substrate remains in large excess throughout?

(A) V_{max} is reached at exactly the same rate as before

(B) The initial rate roughly doubles

(C) The initial rate is unaffected, only V_{max} changes

(D) Rate becomes independent of enzyme concentration

Lời giải chi tiết

With substrate non-limiting, rate is directly proportional to enzyme concentration: doubling enzyme concentration (doubling the number of active sites available) roughly doubles the initial rate. **(B)**.

Bài tập luyện tập

A tangent to a volume–time graph at the origin passes through $(0\,\text{s}, 0\,\text{cm}^3)$ and $(30\,\text{s}, 15\,\text{cm}^3)$. Calculate the initial rate in cm^3/s and in cm^3/min.

Lời giải chi tiết

Initial rate $= \dfrac{15-0}{30-0} = 0.50\,\text{cm}^3/\text{s}$. Per minute: $0.50 \times 60 =$ **30** cm^3/min.

Bài tập luyện tập

Why must the initial rate of an enzyme reaction be found from a *tangent at the origin* rather than simply dividing the total volume of product by the total time of the reaction?

Lời giải chi tiết

The rate of an enzyme reaction is not constant – it decreases over time as substrate is used up (and, in some experiments, as product may inhibit the reaction). Dividing total volume by total time gives only an *average* rate over the whole reaction, which underestimates the true rate at the start. The tangent at $t = 0$ gives the gradient of the curve at that exact instant – the true initial rate, when substrate concentration is still at its original (highest) value – allowing fair comparison between different experimental conditions that all start at the same substrate concentration.

Bài tập luyện tập

Catalase produces $32\,\text{cm}^3$ of O_2 in the first 80 seconds of a reaction. Calculate the initial rate in cm^3/min.

(A) $0.40\ \text{cm}^3/\text{min}$

(B) $24\ \text{cm}^3/\text{min}$

(C) $2.4\ \text{cm}^3/\text{min}$

(D) $40\ \text{cm}^3/\text{min}$

Lời giải chi tiết

Rate $= \dfrac{32}{80} = 0.40\,\text{cm}^3/\text{s}$. Per minute: $0.40 \times 60 =$ **24** cm^3/min. **(B)**.

Bài tập luyện tập

A student states: "a competitive inhibitor permanently lowers the maximum rate a reaction can reach." Evaluate this statement.

Lời giải chi tiết

This statement is **incorrect**. A competitive inhibitor binds reversibly to the active site itself, competing directly with substrate. Because it does not alter the active site's shape or the enzyme's structure, a sufficiently high substrate concentration can out-compete the inhibitor for the active sites, so the same V_{max} can eventually still be reached (just at a higher $[S]$ than without the inhibitor). It is **non-competitive** inhibitors, which distort the active site at an allosteric site, that permanently reduce V_{max} regardless of substrate concentration.

Bài tập luyện tập

Which of the following would most strongly suggest an inhibitor is non-competitive rather than competitive?

(A) Its effect is reduced when substrate concentration is greatly increased

(B) The inhibitor has a molecular structure very similar to the substrate

(C) V_{max} remains lower than the uninhibited reaction even at very high substrate concentrations

(D) The inhibitor binds directly within the active site

Lời giải chi tiết

A permanently lowered V_{max}, even at very high $[S]$, is the diagnostic feature of non-competitive inhibition – the inhibitor distorts the active site at a separate (allosteric) site, so no amount of extra substrate restores full activity to affected enzyme molecules. **(C)**.

Bài tập luyện tập

A non-competitive inhibitor is bound to an enzyme. According to the graph of rate against substrate concentration, what happens to V_{max} compared to the uninhibited reaction?

(A) V_{max} is unchanged, only reached more slowly

(B) V_{max} is reduced, because some enzyme molecules have a permanently distorted active site regardless of substrate concentration

(C) V_{max} increases

(D) There is no such thing as V_{max} for an inhibited reaction

Lời giải chi tiết

Since a non-competitive inhibitor distorts the active site via a separate allosteric site, no amount of extra substrate can restore full activity to the affected enzyme molecules – so the maximum possible rate (V_{max}) is **lowered**, unlike competitive inhibition where V_{max} can still be reached. **(B)**.

Bài tập luyện tập

Explain, using the concept of allosteric sites, how a non-competitive inhibitor can reduce enzyme activity without ever binding the active site.

Lời giải chi tiết

The enzyme's overall three-dimensional (tertiary) structure is a single interconnected folded chain – binding at one location can change the shape at a distant location through altered folding/bond patterns. When a non-competitive inhibitor binds an **allosteric site** (a specific site elsewhere on the enzyme, complementary in shape to the inhibitor), it changes the folding of the polypeptide, which is transmitted through the tertiary structure to distort the shape of the active site itself, even though the inhibitor is bound nowhere near it. The distorted active site can no longer bind substrate efficiently (or at all), reducing the enzyme's activity.

Bài tập luyện tập

In a metabolic pathway $P \rightarrow Q \rightarrow R \rightarrow S$ (each step catalysed by a different enzyme), the end product S is found to inhibit the first enzyme in the pathway. What type of inhibition is this an example of, and what type of feedback does it represent?

(A) Competitive inhibition; positive feedback

(B) Non-competitive (allosteric) inhibition; negative feedback

(C) Competitive inhibition; negative feedback

(D) Non-competitive inhibition; positive feedback

Lời giải chi tiết

The end product binds an allosteric site (not the active site) on the first enzyme, so this is **non-competitive/allosteric inhibition**; because the product acts to reduce further production of itself, it is a form of **negative feedback**. **(B)**.

Bài tập luyện tập

Explain why end-product inhibition typically targets the *first* enzyme of a pathway rather than the last.

Lời giải chi tiết

Inhibiting the first enzyme stops the entire pathway at its earliest point, so no intermediate compounds are wastefully synthesised. If only the *last* enzyme were inhibited, all the earlier steps would continue, and the cell would waste energy and raw materials producing and accumulating intermediate compounds (Q, R, ...) that cannot be converted further – an inefficient use of resources. Targeting the first step is therefore the most economical control point.

Bài tập luyện tập

Which of these is *not* a recognised method of enzyme immobilisation?

(A) Adsorption onto an inert surface

(B) Entrapment within an alginate bead

(C) Covalent bonding to a support material

(D) Dissolving the enzyme freely in the reaction mixture

Lời giải chi tiết

Dissolving the enzyme freely in solution is precisely the *opposite* of immobilisation – it describes a free (non-immobilised) enzyme. The three genuine immobilisation methods are adsorption, entrapment, and covalent bonding (plus membrane/capsule separation). **(D)**.

Bài tập luyện tập

State three advantages of using immobilised rather than free enzymes in an industrial process.

Lời giải chi tiết

Any three of: (1) the enzyme can be **reused** many times (recovered easily from the product), reducing cost; (2) the product is **not contaminated** with dissolved enzyme, so separation/purification is simpler and cheaper; (3) immobilised enzymes are often **more thermally stable** than free enzyme, tolerating slightly higher operating temperatures without denaturing; (4) immobilisation allows **continuous-flow** operation (substrate passed continuously through/over the immobilised enzyme) rather than a stop-start batch process, increasing throughput.

Bài tập luyện tập

In the production of lactose-free milk, why is lactase entrapped in alginate beads rather than simply added directly, free, to the milk?

Lời giải chi tiết

If lactase were added freely to the milk, it would remain dissolved in the final product – it could not be reused for a subsequent batch, and (unless removed by additional purification steps) would remain in the milk itself, which may be undesirable. Entrapping the lactase in porous alginate beads allows milk (and the small lactose, glucose and galactose molecules) to flow through/past the beads and react, while the (larger) enzyme stays trapped inside the bead matrix – so the enzyme is easily recovered, reused for further batches, and never appears in the finished milk.

Bài tập luyện tập

A packed column of immobilised lactase processes milk continuously at $80\ \text{dm}^3/\text{h}$ for 20 hours per day. Calculate the volume of milk processed in a 7-day week.

(A) $1600\ \text{dm}^3$
(B) $11\,200\ \text{dm}^3$
(C) $560\ \text{dm}^3$
(D) $16\,000\ \text{dm}^3$

Lời giải chi tiết

Volume $= 80\ \text{dm}^3/\text{h} \times 20\ \text{h/day} \times 7\ \text{days} = 80 \times 140 =$ **11 200** dm^3. **(B)**.

Bài tập luyện tập

Explain why an immobilised enzyme may show greater thermal stability than the same enzyme free in solution.

Lời giải chi tiết

Being physically attached to, or trapped within, a rigid support structure restricts the extent to which the enzyme's polypeptide chain can vibrate, unfold, and lose its tertiary structure at raised temperature – the support helps to hold the folded shape in place. This means a higher temperature is needed before the weak hydrogen/ionic bonds maintaining the enzyme's shape are sufficiently disrupted for denaturation to occur, compared with the same enzyme moving freely in solution.

Bài tập luyện tập

An enzyme has an optimum temperature of $45\,^{\circ}$C. At $25\,^{\circ}$C its rate is $3.0\,\text{cm}^3$/min, and $Q_{10} \approx 2$ over this range. Estimate the rate at $45\,^{\circ}$C, and explain why this simple Q_{10} doubling rule cannot be used to predict the rate at $65\,^{\circ}$C.

Lời giải chi tiết

$45-25 = 20\,^{\circ}$C rise = two $10\,^{\circ}$C steps: rate $\approx 3.0\times2\times2 =$ **12.0** cm^3/min at $45\,^{\circ}$C (the optimum). The Q_{10} doubling rule only applies *below* the optimum temperature, where rising kinetic energy simply increases the frequency of successful collisions. At $65\,^{\circ}$C, well above the $45\,^{\circ}$C optimum, the enzyme would already be significantly (or fully) **denatured** – an increasing proportion of active sites are destroyed, so rate would be far *lower* than a naive Q_{10} prediction, not higher.

Bài tập luyện tập

A reaction mixture contains enzyme and substrate at a fixed concentration. A competitive inhibitor is added. Which single change to the experiment would allow you to demonstrate that the inhibitor is competitive rather than non-competitive?

(A) Lower the temperature and observe if rate changes

(B) Repeat the experiment across a range of substrate concentrations up to a large excess, and compare the V_{max} reached with and without inhibitor

(C) Measure the pH of the solution

(D) Double the volume of the reaction mixture

Lời giải chi tiết

The defining test is whether V_{max} can still be reached at sufficiently high substrate concentration. If, at very high $[S]$, the inhibited reaction reaches the *same* V_{max} as the uninhibited reaction, the inhibitor is competitive (overcome by excess substrate). If V_{max} remains lower even at very high $[S]$, the inhibitor is non-competitive. **(B)**.

Bài tập luyện tập

Explain why increasing substrate concentration cannot restore the rate of a reaction inhibited by a non-competitive inhibitor, even when substrate is added in very large excess.

Lời giải chi tiết

A non-competitive inhibitor does not occupy or compete for the active site at all – it binds a separate allosteric site and distorts the active site's shape indirectly, through changes transmitted via the enzyme's folded tertiary structure. Since substrate and inhibitor are not competing

for the same binding location, adding more substrate cannot displace the inhibitor or prevent it from binding; the affected enzyme molecules remain non-functional regardless of how much substrate is present, so V_{max} stays reduced.

Bài tập luyện tập

A student measures rate of reaction against substrate concentration for an enzyme at $20\,^{\circ}$C and again at $40\,^{\circ}$C (below the enzyme's optimum of $50\,^{\circ}$C). Describe how the two curves would differ.

Lời giải chi tiết

Both curves would show the same general shape – rate rising with $[S]$ and levelling off at a V_{max} – but the $40\,^{\circ}$C curve would lie **above** the $20\,^{\circ}$C curve at every substrate concentration, reaching a **higher** V_{max}, because higher (but still sub-optimal) temperature increases kinetic energy and collision frequency between enzyme and substrate without yet causing denaturation.

Bài tập luyện tập

Which of the following best describes why enzymes are described as having "specificity"?

(A) Each enzyme can catalyse any reaction, given enough time

(B) The shape and chemical properties of the active site are complementary to only one substrate (or a small group of related substrates)

(C) Enzymes only work at one specific temperature

(D) Enzymes are only found in one specific organ

Lời giải chi tiết

Specificity arises because the active site's shape and the chemical groups lining it (capable of specific hydrogen, ionic, or hydrophobic interactions) are complementary to only one substrate, or a small group of very similarly shaped substrates – not because of temperature or location. **(B)**.

CAMBRIDGE INTERNATIONAL AS & A LEVEL • Unit 4

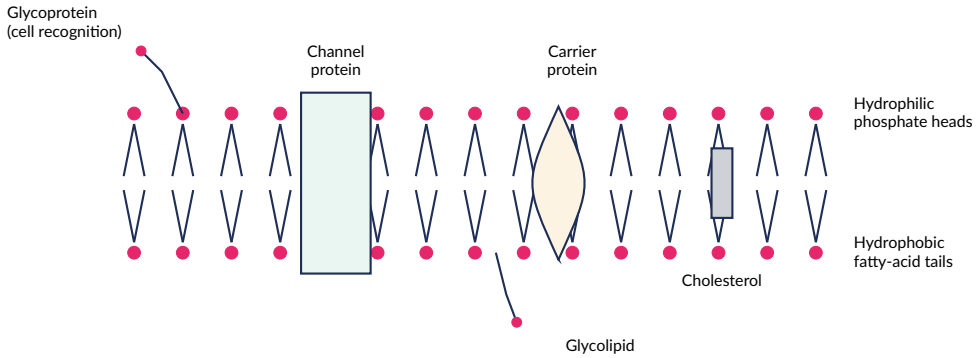
Cell Membranes and Transport

AS Level

Mục tiêu Unit: Mô hình khảm động (fluid mosaic model) và vai trò của phospholipid, protein, cholesterol, glycoprotein/glycolipid trong màng sinh chất; khuếch tán đơn giản và khuếch tán tăng cường; thẩm thấu và thế nước ($\Psi = \Psi_s + \Psi_p$); trạng thái tế bào thực vật/động vật trong các dung dịch khác nhau và phương pháp xác định thế nước bằng thay đổi khối lượng; vận chuyển chủ động, đồng vận chuyển (co-transport) và vận chuyển khối lớn (nhập bào/xuất bào); ảnh hưởng của nhiệt độ lên tính thấm màng (thực hành củ dền) và tỉ lệ diện tích bề mặt : thể tích (SA:V) đối với tốc độ trao đổi chất qua màng.

4.1 The Fluid Mosaic Model

The plasma membrane surrounding every cell, and the internal membranes of organelles, is described by the **fluid mosaic model** (Singer and Nicolson, 1972). Its basic structure is a **phospholipid bilayer**: each phospholipid has a hydrophilic (water-attracting) phosphate "head" and two hydrophobic (water-repelling) fatty-acid "tails". In water, phospholipids spontaneously arrange into a bilayer with the hydrophilic heads facing the aqueous cytoplasm and extracellular fluid on either side, and the hydrophobic tails facing each other in the interior, shielded from water.



The fluid mosaic model (Singer–Nicolson): a phospholipid bilayer embedded with integral proteins (channel/carrier), peripheral proteins, cholesterol, and glycoproteins/glycolipids projecting into the extracellular fluid.

Why "fluid" and why "mosaic"?

Fluid: phospholipids (and most proteins) are not fixed in place – they move and rotate freely within their own layer of the bilayer (lateral movement), giving the membrane the properties of a two-dimensional fluid rather than a rigid solid sheet. **Mosaic**: proteins of many different shapes and sizes are scattered irregularly, at varying densities, throughout the bilayer – like tiles of different shapes and colours set into a mosaic – rather than forming a uniform, regular layer.

Membrane components and roles:

- **Integral (intrinsic) proteins** span the whole bilayer. **Channel proteins** form water-filled pores for the passive, facilitated diffusion of ions or small polar molecules (some are *gated*, opening/closing in response to a stimulus; others are permanently open/ungated). **Carrier proteins** bind a specific molecule and change shape (conformation) to move it across – used in both facilitated diffusion (passive) and active transport (energy-requiring).
- **Peripheral (extrinsic) proteins** sit on one surface only (often attached to integral proteins or lipid heads), e.g. providing structural support or acting as enzymes/receptors.
- **Cholesterol** molecules sit between the phospholipid tails and regulate membrane **fluidity**: at **high temperature** cholesterol restricts the movement of phospholipids, preventing the membrane from becoming too fluid/leaky; at **low temperature** cholesterol prevents phospholipid tails packing too closely together, stopping the membrane becoming too rigid and maintaining fluidity. Cholesterol therefore stabilises membrane fluidity across a range of temperatures.
- **Glycoproteins** (protein + attached carbohydrate chain) and **glycolipids** (lipid + attached carbohydrate chain) project from the outer surface only. They function in **cell signalling/recognition** (e.g. acting as receptors for hormones or neurotransmitters) and as **antigens** that identify the cell as "self" to the immune system (e.g. ABO blood group antigens, and the recognition markers that allow immune cells to distinguish body cells from pathogens or transplanted tissue).

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Mô hình **khảm động (fluid mosaic model)**: màng sinh chất là lớp kép phospholipid (phospholipid bilayer) với đầu ưa nước (hydrophilic) hướng ra ngoài và đuôi kỵ nước (hydrophobic) hướng vào trong. Gọi là "động" (fluid) vì các phospholipid di chuyển tự do trong mặt phẳng màng; gọi là "khảm" (mosaic) vì các protein có kích thước, hình dạng khác nhau nằm rải rác không đều trong màng. **Cholesterol** điều hòa độ linh động của màng: ở nhiệt độ cao, cholesterol hạn chế chuyển động của phospholipid (màng không quá "lỏng"); ở nhiệt độ thấp, cholesterol ngăn các đuôi phospholipid xếp quá sát nhau (màng không quá "cứng"). **Glycoprotein/glycolipid** đóng vai trò nhận diện tế bào và tín hiệu tế bào (ví dụ: kháng nguyên nhóm máu).

(!) Lỗi thường gặp: Đừng viết cholesterol chỉ có *một* tác dụng "làm màng ổn định hơn" một cách chung chung – cần nêu rõ **cả hai chiều**: ở nhiệt độ **cao**, cholesterol làm màng **kém linh động hơn** (hạn chế rò rỉ); ở nhiệt độ **thấp**, cholesterol làm màng **linh động hơn** (ngăn đóng băng/cứng lại). Đây là hai tác dụng đối lập tùy điều kiện nhiệt độ, không phải một chiều duy nhất.

4.2 Passive Transport: Diffusion

4.2.1 Simple diffusion

Diffusion is the net movement of molecules or ions from a region of their higher concentration to a region of their lower concentration, down a **concentration gradient**, as a result of the random (kinetic) motion of particles. It requires no metabolic energy (no ATP) – it is a **passive** process. Small, non-polar or lipid-soluble molecules (e.g. O2, CO2, small steroid hormones) can diffuse directly through the hydrophobic interior of the phospholipid bilayer.

The **rate of simple diffusion** increases with: (1) a **steeper concentration gradient** (bigger difference in concentration between the two sides); (2) a larger **surface area** available for exchange; (3) a shorter **diffusion distance** (thinner membrane/exchange surface); and (4) higher **temperature** (particles have more kinetic energy and move faster). These relationships are summarised qualitatively by **Fick's law**: $\text{rate of diffusion} \propto \dfrac{\text{surface area} \times \text{concentration difference}}{\text{diffusion distance}}$.

Ví dụ mẫu · Applying Fick's law qualitatively

Explain why gas exchange in the alveoli of the lungs is efficient, in terms of the factors that affect the rate of diffusion.

The alveoli provide a very large total **surface area** (many millions of tiny alveoli); the alveolar epithelium and adjacent capillary wall are each only one cell thick, giving a very short **diffusion distance/pathway**; continuous blood flow and ventilation maintain a steep **concentration gradient** for O2 and CO2 between alveolar air and blood; and body temperature ($37\,^{\circ}$C) gives molecules substantial kinetic energy. Together, by Fick's law, these factors maximise the rate of diffusion of respiratory gases.

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Khuếch tán đơn giản (simple diffusion) là sự di chuyển ròng của phân tử/ion từ nơi nồng độ cao đến nơi nồng độ thấp, theo chuyển động nhiệt ngẫu nhiên, **không cần ATP**. Tốc độ khuếch tán tăng khi: chênh lệch nồng độ lớn hơn, diện tích bề mặt trao đổi lớn hơn, quãng đường khuếch tán ngắn hơn, và nhiệt độ cao hơn – được tóm tắt định tính qua **định luật Fick**.

4.2.2 Facilitated diffusion

Larger or polar/charged molecules (e.g. glucose, amino acids, ions such as $Na+$, $K+$, $Cl-$) cannot cross the hydrophobic bilayer interior directly. Instead they cross via specific transport proteins in a process called **facilitated diffusion** – still entirely passive (down the concentration gradient, requiring **no ATP**), but faster than unassisted diffusion through lipid.

- **Channel proteins** form a hydrophilic pore through the membrane. Some are permanently open (**ungated**), allowing continuous passage of specific ions; others are **gated**, opening only in response to a stimulus (e.g. voltage-gated $Na+$ channels in neurones, or ligand-gated channels that open when a signalling molecule binds).
- **Carrier proteins** bind a specific larger polar molecule (e.g. glucose) on one side, then undergo a **conformational change** (change of shape) that moves the molecule through and releases it on the other side, still moving down its concentration gradient.

(!) Lỗi thường gặp: "Khuếch tán tăng cường" (facilitated diffusion) vẫn là khuếch tán **thụ động** (theo chiều gradient nồng độ, **không dùng ATP**) – chỉ khác khuếch tán đơn giản ở chỗ có protein kênh hoặc protein mang hỗ trợ vận chuyển các phân tử lớn/phân cực không thể tự khuếch tán qua lớp lipid kép. Đừng nhầm với vận chuyển chủ động (ngược chiều gradient, **cần ATP**).

4.3 Osmosis and Water Potential

Osmosis is the net movement of **water** molecules from a region of higher water potential to a region of lower water potential, through a partially permeable membrane – a special case of diffusion applied specifically to water.

Water potential (Ψ, measured in kPa) is the tendency of water to move out of a solution; the higher (less negative) the water potential, the greater that tendency. Pure water at atmospheric pressure has the highest possible water potential, defined as $\Psi = 0$. Dissolving any solute lowers water potential (makes it more negative), so every solution has $\Psi < 0$. Water always moves from a region of **higher** Ψ to a region of **lower** Ψ.
For a walled plant cell, $\Psi = \Psi_s + \Psi_p$, where Ψ_s is the **solute potential** (always ≤ 0, more negative with more dissolved solute – water "wants" to move in) and Ψ_p is the **pressure potential** (usually ≥ 0 in a walled cell, the physical pressure exerted by the cell contents pressing outward against the resisting cell wall, which "pushes" water back out).

Water moves from Cell A ($\Psi = -600$ kPa) toward Solution B ($\Psi = -350$ kPa), because -350 kPa is the *higher* (less negative) water potential – water leaves Cell A by osmosis.

Ví dụ mẫu · Water potential calculation 1

A plant cell has solute potential $\Psi_s = -900$ kPa and pressure potential $\Psi_p = +300$ kPa. It is placed in a solution of water potential -500 kPa. Predict the direction of net water movement.

Cell's $\Psi = \Psi_s + \Psi_p = -900 + 300 = -600$ kPa. The external solution (-500 kPa) has a *higher* (less negative) water potential than the cell (-600 kPa), so water moves **into the cell** by osmosis, down the water potential gradient.

Ví dụ mẫu · Water potential calculation 2

A plant cell has $\Psi_s = -1200$ kPa and $\Psi_p = +450$ kPa. It is placed in a sucrose solution of water potential -950 kPa. State and explain the direction of net water movement, and predict the qualitative change in Ψ_p as the cell approaches equilibrium.

Cell's $\Psi = -1200 + 450 = -750$ kPa. The external solution (-950 kPa) has a *lower* (more negative) water potential than the cell (-750 kPa), so water moves **out of the cell** by osmosis. As water leaves, the cell's contents shrink away from the (relatively rigid) wall, so Ψ_p **falls** (less outward pressure on the wall) and Ψ_s becomes more negative (solutes more concentrated as volume falls) until the cell's Ψ equals -950 kPa and net movement stops (equilibrium).

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Thế nước (Ψ) của tế bào thực vật = thế thẩm thấu Ψ_s (luôn ≤ 0, do chất tan) cộng thế áp suất Ψ_p (thường ≥ 0 ở tế bào có thành, do thành tế bào tạo phản lực chống lại nước đi vào). Nước tinh khiết có $\Psi = 0$; mọi dung dịch đều có $\Psi < 0$. Nước luôn di chuyển từ nơi có Ψ **cao hơn** (ít âm hơn) đến nơi có Ψ **thấp hơn** (âm hơn) – không phải theo "nồng độ chất tan" một cách trực tiếp mà theo thế nước tổng.

4.3.1 Plant and animal cells in solutions of varying water potential

Because a plant cell has a semi-rigid **cellulose cell wall**, it can withstand considerable internal (turgor) pressure without bursting; an animal cell, lacking a wall, cannot.

State	Conditions	Description
Turgid (plant)	Placed in pure water / a solution of higher Ψ than the cell	Water enters by osmosis; the protoplast presses outward against the cell wall, which resists further expansion (Ψ_p high, positive) – the cell becomes firm (turgid) but does not burst
Flaccid (plant)	Placed in a solution with Ψ close to the cell's own Ψ	Little or no net water movement; the protoplast still touches the wall but exerts little/no outward pressure ($\Psi_p \approx 0$)
Incipient plasmolysis (plant)	The exact point at which the protoplast just begins to pull away from the wall	$\Psi_p = 0$; the boundary between flaccid and plasmolysed states
Plasmolysed (plant)	Placed in a solution of lower Ψ than the cell (hypertonic)	Water leaves by osmosis; the protoplast shrinks and pulls fully away from the cell wall ($\Psi_p = 0$, cell $\Psi = \Psi_s$ only)
Lysis (animal)	Placed in a solution of higher Ψ than the cytoplasm (hypotonic)	Water enters by osmosis; with no wall to resist, the cell swells and its membrane eventually **bursts**
Crenation (animal)	Placed in a solution of lower Ψ than the cytoplasm (hypertonic)	Water leaves by osmosis; with no wall, the cell shrinks and its membrane becomes shrivelled/wrinkled

States of plant and animal cells in solutions of varying water potential relative to the cell.

Ví dụ mẫu · Animal cell in a hypertonic solution

A red blood cell (no cell wall) is placed in a solution more concentrated (lower Ψ) than its cytoplasm. Describe and explain what happens.

The external solution has a lower (more negative) water potential than the cytoplasm, so water leaves the cell by osmosis, down the water potential gradient. With no cell wall to resist shrinkage or provide a pressure potential, the cell progressively shrinks and its membrane becomes shrivelled – this is called **crenation**.

4.3.2 Practical determination of the water potential of plant tissue

The water potential of a plant tissue (e.g. potato) can be estimated using the **mass-change method**:

1. Cut several cylinders of identical size from the tissue using a cork borer, blot dry, and weigh each accurately.
2. Immerse each cylinder in a different sucrose solution of known, accurately-prepared concentration (e.g. 0.0, 0.2, 0.4, 0.6, 0.8, 1.0 mol/dm^3), keeping temperature and immersion time constant across all tubes.
3. After a fixed time (long enough to approach equilibrium, e.g. 30–60 minutes), remove each cylinder, blot dry, and reweigh.
4. Calculate the **percentage change in mass** for each concentration: $\%\,\text{change} = \dfrac{\text{final mass} - \text{initial mass}}{\text{initial mass}} \times 100$.
5. Plot percentage change in mass (y-axis) against sucrose concentration (x-axis) and draw a line of best fit. The concentration at which the line crosses **zero percentage change** (the x-intercept) is the sucrose concentration whose water potential equals that of the tissue – at this concentration there is no net water movement into or out of the tissue.
6. Using a reference calibration curve/table relating sucrose concentration to water potential, convert this concentration into a water potential value for the tissue.

Ví dụ mẫu · Mass-change practical – worked example

Cylinders of potato tissue are weighed before and after 40 minutes' immersion in sucrose solutions of increasing concentration:

Concentration (mol/dm^3)	Initial mass (g)	Final mass (g)	% change
0.0	5.20	5.61	
0.2	5.15	5.36	
0.4	5.24	5.24	
0.6	5.10	4.87	
0.8	5.30	4.87	

Calculate the missing percentage changes, and estimate the sucrose concentration at which there is zero net water movement.

$\%\text{ change} = \dfrac{\text{final} - \text{initial}}{\text{initial}} \times 100$:

0.0 M: $\dfrac{5.61 - 5.20}{5.20} \times 100 = +7.9\%$. 0.2 M: $\dfrac{5.36 - 5.15}{5.15} \times 100 = +4.1\%$.

0.4 M: $\dfrac{5.24 - 5.24}{5.24} \times 100 = 0.0\%$. 0.6 M: $\dfrac{4.87 - 5.10}{5.10} \times 100 = -4.5\%$. 0.8 M: $\dfrac{4.87 - 5.30}{5.30} \times 100 = -8.1\%$.

The percentage change is already exactly 0% at 0.4 mol/dm^3, so this is the concentration at which the sucrose solution's water potential equals that of the potato tissue – no net water movement occurs (the tissue is neither gaining nor losing water). A reference calibration curve for that sucrose concentration would then be used to read off the corresponding water potential value in kPa.

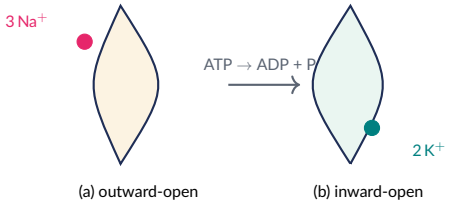
VN **GIẢI THÍCH TIẾNG VIỆT**

Phương pháp **đo thay đổi khối lượng (mass-change method)** xác định thế nước của mô thực vật: ngâm các mẫu mô (kích thước như nhau) vào các dung dịch đường có nồng độ đã biết khác nhau, cân trước và sau, tính **% thay đổi khối lượng**, vẽ đồ thị % thay đổi theo nồng độ, tìm nồng độ tại đó đường biểu diễn cắt trục hoành (% thay đổi $= 0$) – đó chính là nồng độ dung dịch có thế nước **bằng** thế nước của mô. Sau đó dùng đường chuẩn (calibration curve) để chuyển nồng độ này thành giá trị thế nước (kPa).

(!) Lỗi thường gặp: Nếu khối lượng mô **tăng** sau khi ngâm, nghĩa là nước đã đi **vào** mô – thế nước của dung dịch **cao hơn** (ít âm hơn) thế nước của mô. Nếu khối lượng **giảm**, nước đã đi **ra**, nghĩa là thế nước của dung dịch **thấp hơn** mô. Đừng nhầm chiều: khối lượng tăng $\neq$ dung dịch có thế nước thấp hơn.

4.4 Active Transport and Co-transport

Active transport is the movement of molecules or ions **against** their concentration gradient (from a region of lower to higher concentration), using metabolic energy in the form of **ATP**, via specific **carrier proteins**. ATP hydrolysis causes the carrier protein to change **conformation** (shape), physically moving the bound molecule/ion across the membrane against its gradient, then returning to its original shape ready to bind the next molecule.



The sodium–potassium pump: ATP hydrolysis drives a conformational change from (a) an outward-open state, which releases $3\,\mathrm{Na}^+$ to the outside, to (b) an inward-open state, which binds and releases $2\,\mathrm{K}^+$ to the inside – both ions moved against their own concentration gradients.

The **sodium–potassium pump** is a classic example of active transport: for each ATP molecule hydrolysed, it pumps $3\,\mathrm{Na}+$ ions **out** of the cell and $2\,\mathrm{K}+$ ions **in**, both against their concentration gradients. This maintains a high Na+ concentration outside the cell and a high K+ concentration inside – essential for processes including nerve impulse transmission and (as below) co-transport.

Co-transport couples the movement of one substance down its concentration gradient to the simultaneous movement of another substance against its own gradient, via a single carrier protein (a **symport**). In the small intestine and kidney, glucose is absorbed by **co-transport with** Na+: a basolateral sodium–potassium pump continually pumps Na+ out of the epithelial cell into the blood, maintaining a low intracellular Na+ concentration and therefore a steep gradient favouring Na+ entry from the gut lumen (or kidney filtrate). A co-transporter protein in the luminal (apical) membrane allows Na+ to move back into the cell down this gradient *only if* glucose binds simultaneously – so glucose is dragged into the cell *against* its own concentration gradient, powered indirectly by the Na+ gradient (which itself was set up using ATP). Glucose then leaves the cell into the blood via a separate carrier protein by facilitated diffusion, down its own concentration gradient.

VN **GIẢI THÍCH TIẾNG VIỆT**

Vận chuyển chủ động (active transport) di chuyển phân tử/ion **ngược chiều** gradient nồng độ, dùng **ATP** và protein mang đặc hiệu đổi hình dạng (conformation). **Bơm $\mathrm{Na}^+/\mathrm{K}^+$**: mỗi ATP thủy phân bơm $3\,\mathrm{Na}^+$ ra ngoài và $2\,\mathrm{K}^+$ vào trong tế bào. **Đồng vận chuyển (co-transport)**: glucose được hấp thu vào tế bào biểu mô ruột/ống thận *cùng* với Na^+ qua một protein mang duy nhất (symport) – Na^+ đi theo chiều gradient của nó (gradient này được duy trì nhờ bơm $\mathrm{Na}^+/\mathrm{K}^+$ dùng ATP ở màng đáy-bên) "kéo theo" glucose đi ngược chiều gradient của glucose. Đây là vận chuyển chủ động **gián tiếp** (secondary active transport) vì bản thân bước đồng vận chuyển không trực tiếp dùng ATP.

Ví dụ mẫu · Sodium–potassium pump stoichiometry

A cell's sodium–potassium pumps hydrolyse ATP at a rate of 2.0×10^6 molecules per second. Calculate the number of Na+ ions pumped out and K+ ions pumped in per second.

Each ATP hydrolysed pumps $3\,\mathrm{Na}+$ out and $2\,\mathrm{K}+$ in.
Na+ pumped out $= 2.0 \times 10^6 \times 3 =$ **6.0×10^6** ions/s.
K+ pumped in $= 2.0 \times 10^6 \times 2 =$ **4.0×10^6** ions/s.

Ví dụ mẫu · Identifying active transport vs facilitated diffusion from data

An investigator finds that a substance continues to accumulate inside cells even when its external concentration is far lower than the internal concentration, but only while the cells are respiring aerobically; if a respiratory poison is added, net uptake stops. Identify the transport mechanism and justify your answer.

Since the substance moves *against* its concentration gradient (accumulating inside despite lower outside concentration) and this movement stops when aerobic respiration – and therefore ATP production – is blocked, this is **active transport**. Facilitated diffusion could not explain net movement against a concentration gradient, nor would it depend on continued ATP supply.

4.5 Bulk Transport: Endocytosis and Exocytosis

Some substances are too large, or too many molecules at once, to cross the membrane individually via channel or carrier proteins. These are moved by **bulk transport**, which involves the membrane itself forming vesicles, and (like active transport) requires **ATP**.

Endocytosis: the cell membrane invaginates (folds inward) around extracellular material and pinches off, forming a vesicle that brings the material **into** the cell. **Phagocytosis** ("cell eating") takes in large solid particles or whole cells (e.g. a macrophage engulfing a bacterium); **pinocytosis** ("cell drinking") takes in droplets of extracellular fluid and dissolved solutes. **Exocytosis**: intracellular vesicles (often from the Golgi body) move to and fuse with the cell membrane, releasing their contents to the **outside** of the cell (e.g. secretion of digestive enzymes, or neurotransmitter release at a synapse).

VN GIẢI THÍCH TIẾNG VIỆT

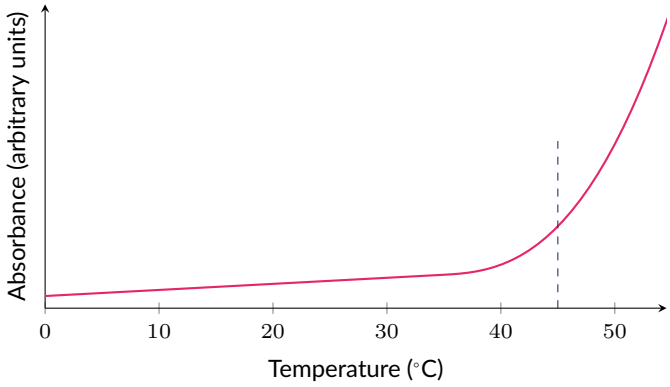
Nhập bào (endocytosis): màng tế bào lõm vào bao lấy vật chất bên ngoài rồi tách ra thành túi (vesicle) đưa vật chất vào trong tế bào – gồm **thực bào (phagocytosis)** (nuốt hạt rắn/tế bào lớn) và **ẩm bào (pinocytosis)** (nuốt giọt dịch ngoại bào). **Xuất bào (exocytosis)**: túi nội bào di chuyển ra và hợp nhất với màng tế bào, giải phóng nội dung ra ngoài. Cả hai đều cần **ATP** và đều liên quan đến sự biến dạng/di chuyển của màng dưới dạng túi (vesicle-mediated).

4.6 Membrane Permeability and Temperature: the Beetroot Practical

Beetroot (*Beta vulgaris*) tissue stores a red pigment, **betalain**, within the central vacuole. In an intact cell, the plasma membrane and the tonoplast (vacuole membrane) normally retain betalain inside the vacuole. This makes beetroot a convenient model for investigating how temperature affects membrane permeability.

Method (outline): cut identical cylinders of beetroot, rinse thoroughly to remove pigment released by cutting, then place separate cylinders into water baths at a range of temperatures (e.g. 10, 20, ..., $70\,^{\circ}$C) for a fixed time. Remove, and measure the **absorbance** of the surrounding water (now tinted by leaked betalain) using a **colorimeter**, at a wavelength appropriate to betalain's absorption maximum. A higher absorbance indicates more pigment has leaked out, i.e. greater membrane permeability/damage.

As temperature rises, increasing kinetic energy causes membrane phospholipids to move more vigorously, disrupting the precise packing of the bilayer; membrane proteins (including those maintaining membrane integrity and structure) begin to **denature** as hydrogen and ionic bonds maintaining their tertiary structure break. Together, these effects increase the permeability of both the plasma membrane and tonoplast, allowing betalain to leak out of the vacuole and cell into the surrounding water. Above roughly 40–$50\,^{\circ}$C this effect becomes pronounced and accelerates sharply, since a growing proportion of membrane proteins are denatured and the ordered lipid bilayer structure becomes substantially disrupted.



Absorbance of the surrounding water (pigment leakage) against beetroot incubation temperature: a slow rise at low temperature, then a sharp increase above roughly 40–$45\,^{\circ}$C as membrane proteins denature and the phospholipid bilayer is increasingly disrupted, releasing progressively more betalain.

Ví dụ mẫu · Interpreting beetroot absorbance data

Absorbance readings for beetroot cylinders incubated for 20 minutes at various temperatures are: $20\,^{\circ}$C: 0.06; $40\,^{\circ}$C: 0.10; $50\,^{\circ}$C: 0.30; $60\,^{\circ}$C: 0.62; $70\,^{\circ}$C: 0.88. Describe the trend and explain it in terms of membrane structure.

Absorbance rises only slightly between 20 and $40\,^{\circ}$C (from 0.06 to 0.10), then rises sharply and continuously from 40 to $70\,^{\circ}$C (from 0.10 to 0.88, roughly a ninefold increase). Below about $40\,^{\circ}$C, membranes remain largely intact and pigment leakage is low. Above this range, heat increasingly disrupts the phospholipid bilayer's packing and denatures membrane proteins (breaking the hydrogen/ionic bonds maintaining their tertiary structure), progressively increasing membrane permeability – so more betalain pigment diffuses out of the vacuole and cell into the surrounding water at each higher temperature, giving a steadily rising absorbance.

VN **GIẢI THÍCH TIẾNG VIỆT**

Thực hành **củ dền (beetroot)**: sắc tố **betalain** bình thường được giữ trong không bào. Khi nhiệt độ tăng, phospholipid chuyển động mạnh hơn làm rối loạn cấu trúc lớp kép, đồng thời protein màng bị **biến tính** (đứt liên kết hydro/ion duy trì cấu trúc bậc ba) – cả hai làm **tăng tính thấm của màng**, khiến betalain rò rỉ ra ngoài. Đo **độ hấp thụ ánh sáng (absorbance)** của nước xung quanh bằng máy so màu (colorimeter) cho biết lượng sắc tố đã rò rỉ – absorbance càng cao, màng càng bị tổn hại nhiều.

(!) Lỗi thường gặp: Đừng chỉ viết "nhiệt độ cao làm màng bị hỏng" một cách chung chung – cần nêu **hai cơ chế cụ thể**: (1) phospholipid chuyển động mạnh hơn, phá vỡ sự sắp xếp trật tự của lớp kép; (2) protein màng bị **biến tính** do đứt liên kết hydro/ion. Cả hai cùng làm tăng tính thấm màng, không phải chỉ một nguyên nhân.

4.7 Surface Area to Volume Ratio and Rate of Exchange

The rate at which a cell (or organism) can exchange substances (nutrients, gases, wastes) with its environment depends on its **surface area**, but the *demand* for exchange (metabolic rate) depends on its **volume**. As an object gets larger, volume increases faster than surface area, so the **surface area : volume (SA:V) ratio falls** – larger cells/organisms have proportionally less surface available per unit of volume needing to be supplied, making exchange relatively slower and diffusion distances (from surface to centre) relatively longer.

Side length L (mm)	Surface area $= 6L^2$ (mm^2)	Volume $= L^3$ (mm^3)	SA:V ratio	SA:V simplified
1	6	1	6.0 : 1	6 : 1
2	24	8	3.0 : 1	3 : 1
3	54	27	2.0 : 1	2 : 1
4	96	64	1.5 : 1	3 : 2

SA:V ratio for cubes of increasing side length. As side length increases fourfold (1 mm to 4 mm), volume increases 64-fold but surface area only 16-fold, so the SA:V ratio falls from $6:1$ to $1.5:1$.

The classic **agar block practical** demonstrates this directly: agar cubes containing a pH indicator (or, e.g., phenolphthalein made pink by alkali) are cut into different sizes (e.g. side lengths 1, 2, and 3 cm) and immersed in a acid solution (e.g. dilute HCl). The acid diffuses in from all exposed faces and neutralises/decolourises the indicator; cubes are periodically removed, cut in half, and the depth or proportion of the colour change is measured. Because the smaller cube has a much larger SA:V ratio, acid can diffuse into a proportionally greater fraction of its total volume in a given time – the whole small cube decolourises before the larger cube does, even though the diffusion *distance* from any given surface point is identical.

Ví dụ mẫu · SA:V ratio and diffusion in agar cubes

Agar cubes of side length 1 cm and 3 cm both contain the same concentration of indicator. Both are immersed in identical acid solution. Calculate the SA:V ratio of each cube and predict which will fully change colour first, explaining why.

1 cm cube: $SA = 6 \times 1^2 = 6$ cm^2; $V = 1^3 = 1$ cm^3; SA:V $= 6:1$.
3 cm cube: $SA = 6 \times 3^2 = 54$ cm^2; $V = 3^3 = 27$ cm^3; SA:V $= 2:1$.
The 1 cm cube has a 3-times greater SA:V ratio than the 3 cm cube. Although acid diffuses inward from the surface at the same rate (same diffusion distance per unit depth, same concentration gradient) in both cubes, the smaller cube has far more surface area *relative to* the volume that needs to be reached – so the acid can neutralise its entire (smaller) volume much faster. The 1 **cm cube** will fully change colour first.

Ví dụ mẫu · Biological significance of SA:V

Explain why small, simple organisms (e.g. *Amoeba*) can rely on diffusion alone across their body surface for gas exchange, but large, complex organisms (e.g. mammals) cannot.

A small organism has a very high SA:V ratio: a large surface area is available relative to its (small) volume and metabolic demand, and the diffusion distance from surface to any internal point is short, so diffusion alone across the body surface can supply oxygen and remove carbon dioxide fast enough. A large organism has a much lower SA:V ratio (proportionally less surface relative to a far larger metabolically active volume) and, for internal cells, a much greater diffusion distance to the body surface – diffusion alone would be far too slow to meet metabolic demand, which is why large organisms have evolved specialised exchange surfaces (e.g. alveoli, gills) with folding/branching to increase surface area, together with mass-transport systems (e.g. a circulatory system) to move substances the remaining distance quickly.

VN **GIẢI THÍCH TIẾNG VIỆT**

Tỉ lệ **diện tích bề mặt : thể tích (SA:V)** giảm dần khi vật thể/tế bào lớn lên, vì thể tích tăng theo lũy thừa 3 trong khi diện tích bề mặt chỉ tăng theo lũy thừa 2. Sinh vật nhỏ có SA:V cao nên có thể trao đổi chất chỉ bằng khuếch tán qua bề mặt cơ thể; sinh vật lớn có SA:V thấp hơn nên cần **bề mặt trao đổi chuyên biệt** (phế nang, mang cá...) với diện tích lớn hơn nhiều nhờ gấp nếp/phân nhánh, cùng với **hệ vận chuyển khối** (ví dụ hệ tuần hoàn) để bù lại quãng đường

khuếch tán còn lại.

Ôn tập nhanh: Màng khảm động = lớp kép phospholipid + protein (kênh/mang) + cholesterol (điều hòa độ linh động 2 chiều) + glycoprotein/glycolipid (nhận diện). Khuếch tán đơn giản: qua lớp lipid trực tiếp, không ATP. Khuếch tán tăng cường: qua protein kênh/mang, vẫn không ATP. Thẩm thấu: nước di chuyển theo Ψ ($\Psi = \Psi_s + \Psi_p$ ở tế bào có thành); nước tinh khiết $\Psi = 0$. Tế bào thực vật: trương nước (turgid) → mềm (flaccid) → co nguyên sinh tới hạn (incipient plasmolysis) → co nguyên sinh (plasmolysed). Tế bào động vật: trương vỡ (lysis) hoặc co nhăn (crenation). Vận chuyển chủ động: ngược gradient, cần ATP, bơm Na^+/K^+ (3 ra : 2 vào); đồng vận chuyển (co-transport) glucose/Na^+. Nhập bào/xuất bào: cần ATP, qua túi màng. SA:V giảm khi kích thước tăng → ảnh hưởng tốc độ trao đổi chất qua bề mặt.

4.8 Practice Questions

Bài tập luyện tập

Which term best describes the arrangement of proteins within the phospholipid bilayer, according to the fluid mosaic model?

(A) Proteins form a continuous, uniform layer across the entire membrane surface

(B) Proteins are scattered irregularly, at varying densities and of varying shapes/sizes, throughout the bilayer

(C) Proteins are found only on the inner surface of the membrane

(D) Proteins are entirely absent from cell membranes

Lời giải chi tiết

The "mosaic" part of the model refers to proteins of many different shapes and sizes being scattered irregularly (not uniformly or in a fixed pattern) throughout the bilayer, at varying densities. **(B)**.

Bài tập luyện tập

Explain, with reference to phospholipid movement, why the plasma membrane is described as "fluid".

Lời giải chi tiết

Phospholipid molecules (and many proteins) are not fixed rigidly in place – they can move and rotate freely within their own layer of the bilayer (lateral diffusion), and the fatty-acid tails give the interior of the membrane liquid-like properties at normal body temperature. This constant, free movement of components within the plane of the membrane is why it behaves as a two-dimensional fluid rather than a rigid, solid structure.

Bài tập luyện tập

A membrane is exposed to a decrease in temperature. Explain the specific role cholesterol plays in this situation.

Lời giải chi tiết

At lower temperature, phospholipid tails would otherwise pack closely together and the membrane would become too rigid/inflexible. Cholesterol molecules, positioned between the phospholipid tails, physically prevent this close packing, maintaining sufficient space between tails – keeping the membrane appropriately fluid even at reduced temperature.

Bài tập luyện tập

Glycoproteins on the surface of red blood cells determine a person's ABO blood group. What is the primary biological function being illustrated here?

(A) Catalysis of metabolic reactions

(B) Cell signalling and recognition (acting as antigens/identity markers)

(C) Active transport of ions

(D) Structural support of the cytoskeleton

Lời giải chi tiết

Glycoproteins (and glycolipids) projecting from the cell surface commonly act as recognition markers/antigens, allowing cells (and the immune system) to identify cell type or "self" versus "non-self" – as illustrated by ABO blood-group antigens. **(B)**.

Bài tập luyện tập

Using Fick's law, explain why increasing the surface area of an exchange organ increases the rate of diffusion across it.

Lời giải chi tiết

Fick's law states that rate of diffusion is directly proportional to surface area (rate $\propto \frac{\text{surface area} \times \text{concentration difference}}{\text{diffusion distance}}$). A larger surface area provides more area over which molecules can simultaneously cross the membrane at any instant, so for the same concentration gradient and diffusion distance, more molecules diffuse across per unit time – increasing the overall rate.

Bài tập luyện tập

Which of the following is passive (requires no ATP)?

(A) Active transport of Na+ ions against their gradient

(B) Facilitated diffusion of glucose through a carrier protein, down its concentration gradient

(C) Phagocytosis

(D) Exocytosis of secretory vesicles

Lời giải chi tiết

Facilitated diffusion moves substances down their concentration gradient through channel or carrier proteins and requires no ATP, unlike active transport and bulk transport (phagocytosis, exocytosis), which both require ATP. **(B)**.

Bài tập luyện tập

State two differences between a channel protein and a carrier protein involved in facilitated diffusion.

Lời giải chi tiết

Any two of: a channel protein forms a continuous, water-filled pore through the membrane, while a carrier protein binds the specific molecule and changes shape (conformation) to move it across. Some channel proteins are gated (open only in response to a stimulus) while others are permanently open; carrier proteins inherently require a conformational change for every molecule transported. Channel proteins typically transport ions, while carrier proteins commonly transport larger polar molecules such as glucose or amino acids.

Bài tập luyện tập

A plant cell has $\Psi_s = -850$ kPa and $\Psi_p = +200$ kPa. It is placed in a solution of water potential -400 kPa. Calculate the cell's water potential and predict the direction of net water movement.

(A) $\Psi = -650$ kPa; water moves out of the cell

(B) $\Psi = -650$ kPa; water moves into the cell

(C) $\Psi = -1050$ kPa; water moves into the cell

(D) $\Psi = +1050$ kPa; water moves out of the cell

Lời giải chi tiết

Cell $\Psi = \Psi_s + \Psi_p = -850 + 200 = -650$ kPa. The external solution (-400 kPa) has a higher (less negative) water potential than the cell, so water moves **into** the cell. **(B)**.

Bài tập luyện tập

A fully turgid plant cell has $\Psi_s = -1100$ kPa and $\Psi_p = +1100$ kPa. State its overall water potential and explain what this value means physically.

Lời giải chi tiết

$\Psi = \Psi_s + \Psi_p = -1100 + 1100 = 0$ kPa. A fully turgid cell in equilibrium with pure water has $\Psi = 0$, equal to pure water's water potential – meaning there is no further net tendency for water to move into or out of the cell; the inward "pull" of the (fully concentrated) solute potential is exactly balanced by the outward physical push of the cell wall's pressure potential.

Bài tập luyện tập

Which best describes a plant cell at the point of incipient plasmolysis?

(A) Ψ_p is at its maximum positive value

(B) $\Psi_p = 0$; the protoplast is just beginning to pull away from the cell wall

(C) The cell has burst

(D) The cell is fully turgid

Lời giải chi tiết

Incipient plasmolysis is the precise boundary point at which the protoplast just begins to separate from the cell wall; at this point the cell contents are no longer pressing outward on the

wall, so $\Psi_p = 0$. **(B)**.

Bài tập luyện tập

An animal cell (no wall) is placed in pure water. Predict and explain what happens.

Lời giải chi tiết

Pure water has the highest possible water potential ($\Psi = 0$), higher than the cell's cytoplasm (which contains dissolved solutes, so $\Psi < 0$). Water therefore moves into the cell by osmosis, down the water potential gradient. Since the cell has no rigid wall to resist expansion or generate an opposing pressure potential, it continues to swell until the membrane can no longer withstand the internal pressure and the cell **bursts (lyses)**.

Bài tập luyện tập

Potato cylinders of initial mass 6.00 g are immersed in a sucrose solution and, after 1 hour, have a final mass of 5.55 g. Calculate the percentage change in mass.

(A) -7.5%
(B) $+7.5\%$
(C) -0.45%
(D) -45%

Lời giải chi tiết

$$\%\ \text{change} = \frac{5.55 - 6.00}{6.00} \times 100 = \frac{-0.45}{6.00} \times 100 = -\mathbf{7.5}\%.$$ **(A)**.

Bài tập luyện tập

In the mass-change practical for determining water potential, explain why cylinders must be **blotted dry** (surface liquid removed) both before the initial weighing and after the final weighing.

Lời giải chi tiết

Any surface liquid clinging to the cylinder is not part of the tissue itself, but would still add to the recorded mass – an inconsistent film of surface liquid (varying between cylinders, or between the initial and final weighing of the same cylinder) would introduce error unrelated to genuine water movement into or out of the tissue by osmosis. Blotting dry each time ensures the mass recorded reflects only the tissue (and any water absorbed into/lost from its cells), allowing an accurate percentage change in mass to be calculated.

Bài tập luyện tập

In a mass-change experiment, the line of best fit for % change in mass against sucrose concentration crosses zero at 0.35 mol/dm^3. What does this concentration represent?

(A) The concentration of sucrose inside every cell of the tissue

(B) The sucrose concentration whose water potential is exactly equal to the water potential of the tissue

(C) The concentration at which the tissue would burst

(D) An experimental error; concentration should never affect mass change

Lời giải chi tiết

Zero % change in mass means no net water movement occurred – this happens only when the external solution's water potential exactly equals the tissue's own water potential, so there is no net osmotic gradient in either direction. **(B)**.

Bài tập luyện tập

Explain, in terms of carrier protein conformation, how active transport moves a substance against its concentration gradient.

Lời giải chi tiết

A specific carrier protein binds the substance on one side of the membrane, where its concentration is lower. Energy released by ATP hydrolysis (often via phosphorylation of the carrier protein) causes the carrier to undergo a **conformational change** (change of three-dimensional shape), physically carrying the bound substance across the membrane and releasing it on the other side (where its concentration is higher) – moving it against its concentration gradient. The carrier then returns to its original shape, ready to bind another molecule.

Bài tập luyện tập

For every ATP molecule hydrolysed, how many Na+ ions are pumped out and how many K+ ions are pumped in by the sodium–potassium pump?

(A) 2 Na^+ out, 3 K^+ in

(B) 3 Na^+ out, 2 K^+ in

(C) 1 Na^+ out, 1 K^+ in

(D) 3 Na^+ in, 2 K^+ out

Lời giải chi tiết

The sodium–potassium pump moves 3 Na+ ions out of the cell and 2 K+ ions into the cell for every ATP molecule hydrolysed, both against their respective concentration gradients. **(B)**.

Bài tập luyện tập

Glucose is absorbed into gut epithelial cells against its own concentration gradient, co-transported with Na+ ions whose gradient is maintained by a separate ATP-driven pump elsewhere on the cell. What is this overall process called, and why?

(A) Simple diffusion, because glucose moves through the bilayer directly

(B) Facilitated diffusion, because a carrier protein is involved and no ATP is used directly by that carrier

(C) Active transport (indirectly powered by ATP via the maintained Na+ gradient)

(D) Osmosis, because water accompanies the glucose

Lời giải chi tiết

Glucose moves against its own gradient, which requires energy input. Although the glucose/Na+ co-transporter itself does not hydrolyse ATP directly, ATP is used elsewhere (the sodium–potassium pump) to maintain the Na+ gradient that powers this co-transport – overall this is **active transport** (specifically, secondary active transport). **(C)**.

Bài tập luyện tập

A cell's sodium–potassium pumps hydrolyse ATP at 5.0×10^5 molecules per second. Calculate the number of K+ ions pumped into the cell per second.

(A) 1.0×10^6
(B) 1.5×10^6
(C) 5.0×10^5
(D) 2.5×10^5

Lời giải chi tiết

Each ATP hydrolysed pumps 2 K+ ions in: $5.0 \times 10^5 \times 2 = \mathbf{1.0 \times 10^6}$ ions/s. **(A)**.

Bài tập luyện tập

Distinguish between phagocytosis and pinocytosis.

Lời giải chi tiết

Both are forms of endocytosis (bulk uptake, requiring ATP, via membrane invagination and vesicle formation). **Phagocytosis** takes in large solid particles or whole cells (e.g. a macrophage engulfing a bacterium), typically forming a large vesicle (phagosome). **Pinocytosis** takes in small droplets of extracellular fluid together with dissolved solutes, typically via much smaller vesicles, and is not restricted to specialised cells in the way phagocytosis often is.

Bài tập luyện tập

Secretory cells package digestive enzymes into vesicles at the Golgi body, which then fuse with the cell membrane to release the enzymes outside the cell. What is this process, and why does it require ATP?

(A) Endocytosis; ATP is needed to break down the vesicle membrane
(B) Exocytosis; ATP is needed to move vesicles along the cytoskeleton and to fuse the vesicle membrane with the plasma membrane
(C) Facilitated diffusion; ATP powers the carrier protein
(D) Osmosis; ATP powers water movement

Lời giải chi tiết

Vesicles fusing with the membrane to release contents outside the cell is **exocytosis**. ATP is required to actively move vesicles (often along cytoskeletal tracks) to the membrane and to drive the membrane fusion process itself. **(B)**.

Bài tập luyện tập

In the beetroot practical, why must the cylinders be rinsed thoroughly *before* being placed into the water baths?

Lời giải chi tiết

Cutting the beetroot cylinders inevitably ruptures cells at the cut surfaces, releasing some betalain pigment immediately regardless of temperature. Rinsing removes this pigment released purely by the cutting process, so that any pigment subsequently measured in the water baths results specifically from **temperature-induced membrane damage** during incubation, not from the initial cutting – improving the validity of the comparison between temperatures.

Bài tập luyện tập

Explain why absorbance readings in the beetroot practical rise only slowly at low temperatures but increase sharply above roughly 40–$50\,^{\circ}$C.

Lời giải chi tiết

At lower temperatures, the phospholipid bilayer and its associated proteins remain largely intact, so membrane permeability (and hence pigment leakage) stays low and rises only slightly with temperature. Above roughly 40–$50\,^{\circ}$C, an increasing proportion of membrane proteins are **denatured** (hydrogen/ionic bonds maintaining their tertiary structure break) and the ordered arrangement of the phospholipid bilayer becomes substantially disrupted by the greater kinetic energy of the molecules. Both effects sharply and increasingly raise membrane permeability, so betalain leakage – and therefore absorbance – rises steeply once this threshold is passed.

Bài tập luyện tập

Two beetroot cylinders are incubated at $30\,^{\circ}$C and $65\,^{\circ}$C respectively for equal times, and the surrounding water is tested with a colorimeter. Which result would you expect, and why?

(A) Similar absorbance in both, since temperature does not affect membrane permeability

(B) Much higher absorbance at $65\,^{\circ}$C, because greater membrane/protein disruption releases more betalain

(C) Higher absorbance at $30\,^{\circ}$C, because cold denatures membranes more than heat

(D) Zero absorbance at both temperatures, since betalain cannot leave an intact vacuole

Lời giải chi tiết

$65\,^{\circ}$C is well above the threshold at which membrane proteins denature and the phospholipid bilayer is substantially disrupted, so far more betalain leaks out – giving a much higher absorbance than at $30\,^{\circ}$C, where membranes remain largely intact. **(B)**.

Bài tập luyện tập

Calculate the surface area, volume, and SA:V ratio (in simplest form) of a cube with side length 5 mm.

Lời giải chi tiết

$SA = 6L^2 = 6 \times 5^2 = 6 \times 25 = 150\,\text{mm}^2$. $V = L^3 = 5^3 = 125\,\text{mm}^3$. SA:V $= 150 : 125 = 1.2 : 1$ (or $6 : 5$).

Bài tập luyện tập

Which cube has the greatest SA:V ratio?

(A) Side length 1 mm

(B) Side length 2 mm

(C) Side length 4 mm

(D) Side length 8 mm

Lời giải chi tiết

SA:V ratio for a cube $= 6L^2/L^3 = 6/L$, which is largest when L is smallest. The 1 mm cube (SA:V $= 6 : 1$) has the greatest SA:V ratio of the options given. **(A)**.

Bài tập luyện tập

Agar cubes of side 2 cm and 4 cm are placed in identical acid solution. Calculate the SA:V ratio of each and predict which cube would show acid penetration to a greater *proportion* of its total volume after a fixed time.

Lời giải chi tiết

2 cm cube: $SA = 6 \times 2^2 = 24\,\text{cm}^2$; $V = 2^3 = 8\,\text{cm}^3$; SA:V $= 24 : 8 = 3 : 1$.
4 cm cube: $SA = 6 \times 4^2 = 96\,\text{cm}^2$; $V = 4^3 = 64\,\text{cm}^3$; SA:V $= 96 : 64 = 1.5 : 1$.
The 2 cm cube has twice the SA:V ratio of the 4 cm cube. Since acid diffuses inward at the same rate through the same distance from any surface point in both cubes, the smaller cube's greater surface area relative to its (smaller) volume means acid can neutralise a much greater *proportion* of its total volume in the same time. The 2 **cm cube** shows proportionally greater acid penetration.

Bài tập luyện tập

A single-celled organism is spherical with radius $10\,\mu$m; a second is spherical with radius $100\,\mu$m. Explain, in terms of SA:V ratio, why the larger organism is more likely to need specialised exchange structures or a transport system.

Lời giải chi tiết

Since surface area scales with radius squared ($4\pi r^2$) but volume scales with radius cubed ($\frac{4}{3}\pi r^3$), the SA:V ratio scales as $1/r$: increasing radius 10-fold (from 10 to $100\,\mu$m) reduces the SA:V ratio to one-tenth of its original value. The larger organism therefore has proportionally far less surface area available, relative to its (much greater) metabolically active volume and internal diffusion distances, to exchange gases, nutrients and wastes by diffusion alone. To meet its metabolic demand it is likely to require specialised, folded/branched exchange surfaces (increasing surface area) and/or an internal transport (mass-flow) system to move substances the extra distance between the exchange surface and internal cells.

Bài tập luyện tập

Which statement correctly compares facilitated diffusion and active transport?

(A) Both move substances down their concentration gradient and require no ATP

(B) Facilitated diffusion moves substances down their gradient without ATP; active transport moves substances against their gradient using ATP

(C) Facilitated diffusion requires ATP; active transport does not

(D) Both always move substances against their concentration gradient

Lời giải chi tiết

Facilitated diffusion is passive (down the concentration gradient via channel/carrier proteins, no ATP); active transport moves substances against their concentration gradient using specific carrier proteins and ATP. **(B)**.

Bài tập luyện tập

A patient's red blood cells are placed in a saline solution and observed to shrink and become crenated. What can be concluded about the water potential of the saline solution relative to the cytoplasm of the red blood cells?

Lời giải chi tiết

Crenation (shrinking, with a shrivelled membrane) occurs when water leaves an animal cell by osmosis, which happens only when the external solution has a **lower (more negative) water potential** than the cytoplasm. Therefore the saline solution's water potential must be lower than that of the red blood cells' cytoplasm.

The Mitotic Cell Cycle

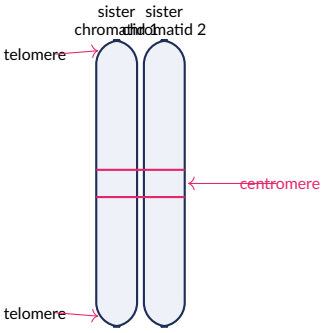
AS Level

Mục tiêu Unit: Cấu trúc nhiễm sắc thể (DNA + protein histone, nhiễm sắc chất, siêu xoắn); các pha của chu kỳ tế bào (G1, S, G2, M) và các điểm kiểm soát (checkpoint); trình tự chi tiết bốn kỳ của nguyên phân và sự phân chia tế bào chất; ý nghĩa sinh học của nguyên phân; cơ chế kiểm soát chu kỳ tế bào (cyclin/CDK) và mối liên hệ với ung thư (tiền gene sinh ung thư, gene ức chế khối u *p53*); chỉ số nguyên phân (mitotic index) và thực hành quan sát đầu rễ hành; tế bào gốc và sự biệt hóa.

5.1 Chromosome structure

Every eukaryotic chromosome is built from a single, extremely long molecule of **DNA** wound around **histone proteins**. Roughly 146 base pairs of DNA wrap almost twice around a cluster of eight histone molecules to form a **nucleosome** — the "beads on a string" level of packaging. Strings of nucleosomes coil further into a thicker **chromatin** fibre, and during cell division this chromatin undergoes additional **supercoiling** (condensation) into the short, thick, readily visible structure recognised under a light microscope as a chromosome. This packaging is essential: fully stretched out, the DNA of a single human cell would be about two metres long, yet it must fit inside a nucleus only a few micrometres across, and it must be organised so that it can be accurately shared between daughter cells.

By the time a cell enters mitosis, each chromosome has already been replicated (during the preceding S phase) and therefore consists of two identical **sister chromatids**, joined together at a single constricted region called the **centromere**. The centromere is also the site where spindle fibres attach (via a protein structure called the kinetochore) during mitosis. At each end of a chromosome lies a **telomere** — a region of short, repetitive, non-coding DNA sequences that protects the coding DNA from being lost or degraded each time the chromosome is copied, and prevents chromosome ends from being mistaken for damaged DNA and fused together.



A replicated chromosome: two genetically identical sister chromatids, produced by DNA replication in S phase, held together at the centromere. Telomeres cap each end.

Levels of DNA packaging

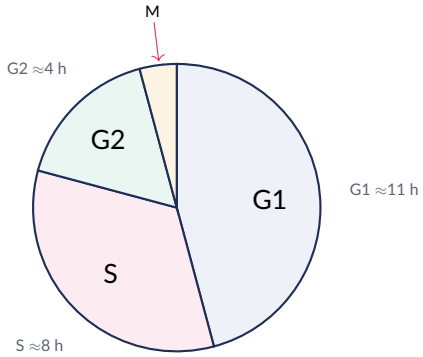
DNA double helix → wraps around histones to form **nucleosomes** ("beads on a string") → nucleosomes coil into a **chromatin** fibre → further looping and **supercoiling** condenses chromatin into the compact **chromosome** visible at mitosis. Between divisions (interphase) chromatin is far less condensed, allowing RNA polymerase and other enzymes access to the DNA for transcription and replication.

VN **GIẢI THÍCH TIẾNG VIỆT**

Mỗi nhiễm sắc thể (NST) là một phân tử DNA rất dài quấn quanh các protein **histone**, tạo thành **nhiễm sắc chất** (chromatin); trong quá trình phân bào, nhiễm sắc chất co xoắn (siêu xoắn) lại thành NST ngắn, đậm đặc, dễ quan sát dưới kính hiển vi. Sau khi nhân đôi DNA (pha S), mỗi NST gồm **2 nhiễm sắc tử chị em** (sister chromatids) giống hệt nhau về mặt di truyền, dính nhau tại **tâm động** (centromere) — vị trí thoi phân bào sẽ bám vào. Hai đầu mút NST là **telomere**, có vai trò bảo vệ NST khỏi bị mất DNA mã hóa hoặc dính vào NST khác.

5.2 The cell cycle

The **cell cycle** is the ordered sequence of events by which a eukaryotic cell grows, replicates its DNA, and divides into two daughter cells. It is divided into **interphase** (further split into G1, S and G2) and **M phase** (mitosis and cytokinesis).



The eukaryotic cell cycle (illustrative proportions for a cultured mammalian cell with a 24-hour cycle: G1 ≈ 11 h, S ≈ 8 h, G2 ≈ 4 h, M ≈ 1 h). Interphase (G1+S+G2) occupies by far the greatest share of the cycle.

The phases of the cell cycle

- **G1 (Gap 1):** the cell grows in size, synthesises proteins and produces new organelles (e.g. mitochondria, ribosomes); the **G1 checkpoint** assesses cell size, nutrient availability, and DNA integrity before committing the cell to replicate its DNA.
- **S (Synthesis): semi-conservative** replication of the entire DNA content occurs (see Unit 6); each chromosome, previously a single DNA molecule, now consists of two identical sister chromatids joined at the centromere. The amount of DNA in the cell doubles.
- **G2 (Gap 2):** further cell growth and protein synthesis (e.g. tubulin for spindle fibres), and final preparation for division; the **G2 checkpoint** verifies that DNA has been replicated completely and accurately, with no remaining damage, before mitosis is allowed to begin.
- **M phase: mitosis** (nuclear division, producing two genetically identical nuclei) followed by **cytokinesis** (division of the cytoplasm into two separate daughter cells).

Interphase (G1 + S + G2) is by far the longest part of the cycle and is metabolically the **most active** phase: the cell is continuously growing, synthesising proteins, replicating organelles and (in S) replicating its entire genome. Cells that stop dividing (e.g. most mature neurons, or cells awaiting a signal to divide) may exit the cycle into a resting state called **G0**; a cell in G0 carries out its normal metabolic functions but does not progress toward division unless stimulated to re-enter G1.

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Chu kỳ tế bào gồm **kỳ trung gian** (interphase: G1, S, G2) và **pha M** (nguyên phân + phân chia tế bào chất). G1: tế bào lớn lên, tổng hợp protein, tạo bào quan mới (có **điểm kiểm soát G1**). S: nhân đôi DNA theo cơ chế bán bảo toàn — mỗi NST từ 1 sợi thành 2 nhiễm sắc tử chị em. G2: tiếp tục lớn lên, tổng hợp protein cần cho phân bào (có **điểm kiểm soát G2**). Kỳ trung gian chiếm phần lớn thời gian chu kỳ và là giai đoạn hoạt động trao đổi chất mạnh nhất — **không phải** là giai đoạn "nghỉ ngơi" như tên gọi dễ gây hiểu lầm. Tế bào ngừng phân chia có thể rời khỏi chu kỳ vào trạng thái nghỉ **G0**.

(!) Lỗi thường gặp: "Interphase" nghe có vẻ là giai đoạn "nghỉ" giữa hai lần phân bào, nhưng thực chất đây là pha **hoạt động mạnh nhất** về mặt trao đổi chất (tổng hợp protein, nhân đôi DNA, nhân đôi bào quan) và chiếm phần lớn thời lượng của cả chu kỳ tế bào (thường trên 90% ở nhiều loại tế bào).

5.3 Mitosis: the four stages

Mitosis is nuclear division that produces two daughter nuclei genetically identical to each other and to the parent nucleus. It is conventionally divided into four continuous stages.

Stage	Key events
Prophase	Chromatin condenses (supercoils) into visible chromosomes, each consisting of two sister chromatids joined at a centromere; the nucleolus disappears; the nuclear envelope breaks down; spindle fibres (composed of microtubules) begin to assemble from opposite poles of the cell. In animal cells, the two centrioles (which duplicated in interphase) migrate to opposite poles, organising the spindle; plant cells lack centrioles but still assemble a functional spindle.
Metaphase	Chromosomes, each still consisting of two sister chromatids, move to and line up individually along the **equator** (metaphase plate) of the spindle, each attached to spindle fibres from both poles via its centromere/kinetochore. The **spindle assembly checkpoint** verifies that every chromosome is correctly attached to spindle fibres from both poles before allowing progression to anaphase — this prevents chromosomes being lost or unequally distributed.
Anaphase	Centromeres split, separating each pair of sister chromatids; spindle fibres shorten (depolymerise), pulling the now-independent chromatids rapidly to opposite poles of the cell. Each separated chromatid is now considered a full chromosome in its own right.
Telophase	Chromosomes arrive at the poles and decondense (uncoil) back into less condensed chromatin; nuclear envelopes reform around each of the two new sets of chromosomes, and nucleoli reappear — producing two genetically identical nuclei within what is still, briefly, one cell.

The four stages of mitosis. A useful mnemonic for the order is *PMAT*: Prophase, Metaphase, Anaphase, Telophase.

Cytokinesis (division of the cytoplasm) follows telophase but is technically distinct from mitosis (which concerns only the nucleus). It occurs differently in animal and plant cells:

- **Animal cells:** a ring of actin and myosin filaments contracts beneath the cell surface membrane, pulling it inward to form a **cleavage furrow** that pinches the cell into two — division proceeds from the *outside in*.
- **Plant cells:** because a rigid cellulose cell wall surrounds the cell, Golgi-derived vesicles carrying cell wall material migrate to the equator and fuse to build a new partition, the **cell plate**, which grows outward and matures into a new cross wall — division proceeds from the *inside out*.

VN **GIẢI THÍCH TIẾNG VIỆT**

Bốn kỳ của nguyên phân theo thứ tự **PMAT**: **Kỳ đầu** (NST co xoắn thành 2 nhiễm sắc tử dính nhau ở tâm động; màng nhân và nhân con biến mất; thoi vô sắc hình thành; ở tế bào động vật, 2 trung thể di chuyển về 2 cực) → **Kỳ giữa** (NST xếp thành một hàng ở mặt phẳng xích đạo, gắn với thoi từ cả hai cực; **điểm kiểm soát thoi phân bào** kiểm tra mọi NST đã gắn đúng trước khi cho phép chuyển sang kỳ sau) → **Kỳ sau** (tâm động tách đôi, nhiễm sắc tử chị em tách nhau, thoi co ngắn kéo chúng về 2 cực đối diện) → **Kỳ cuối** (NST duỗi xoắn, màng nhân tái tạo quanh mỗi bộ NST, tạo 2 nhân con giống hệt nhau). Sau đó là **phân chia tế bào chất**: ở tế bào động vật hình thành **rãnh phân cắt** (co thắt từ ngoài vào nhờ vòng actin–myosin); ở tế bào thực vật hình thành **vách ngăn tế bào** (cell plate, do túi Golgi mang vật liệu vách tế bào tạo nên từ giữa ra ngoài) vì tế bào thực vật có vách cứng bao ngoài không thể co thắt được.

(!) Lỗi thường gặp: Đừng nhầm rằng tế bào thực vật cũng tạo **rãnh phân cắt** như tế bào động vật. Vì có vách tế bào cứng bằng cellulose, tế bào thực vật **không thể** co thắt màng từ ngoài vào; thay vào đó chúng xây một **vách ngăn mới (cell plate)** từ giữa tế bào lan ra hai bên, do các túi Golgi chứa vật liệu vách tế bào hợp nhất lại tạo thành.

Ví dụ mẫu · Predicting the effect of a spindle poison

The drug colchicine prevents microtubules (spindle fibres) from assembling. A population of dividing cells is treated with colchicine just as cells begin prophase. At which stage will affected cells become permanently blocked, and why?

Without spindle fibres, chromosomes cannot be moved to, and cannot become correctly attached at, the metaphase plate. The spindle assembly checkpoint will detect this lack of (or incorrect) attachment and will not permit the transition into anaphase. Cells will therefore progress through prophase (which does not strictly require a completed spindle) but will **arrest at metaphase**, with condensed chromosomes failing to align/attach correctly, unable to proceed to anaphase. (This is precisely why spindle poisons such as colchicine, vincristine and paclitaxel/taxol are used clinically as anti-cancer chemotherapy agents — they selectively block the division of rapidly-dividing tumour cells.)

5.4 Significance of mitosis

Mitosis produces two daughter cells that are **genetically identical** to each other and to the original parent cell (same chromosome number, same alleles) because each daughter receives one complete, identical copy of every chromosome. This makes mitosis the basis of:

- **Growth:** multicellular organisms increase in cell number (and therefore size) through repeated rounds of mitosis from a single fertilised egg.

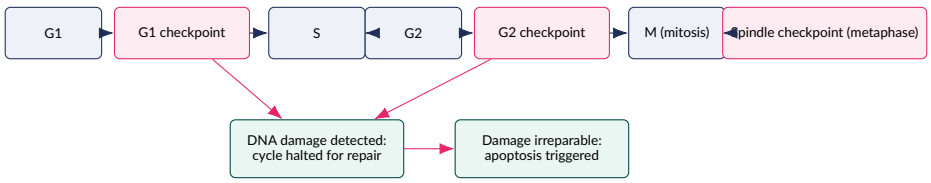
- **Repair and replacement:** damaged or worn-out tissues (e.g. skin, gut lining, blood cells) are replaced by mitotic division of nearby stem/progenitor cells.
- **Asexual reproduction:** many organisms (e.g. many plants via runners/cuttings, some invertebrates via budding or fragmentation, single-celled eukaryotes via binary fission-like division) produce genetically identical offspring entirely through mitosis, without the involvement of gametes.

VN **GIẢI THÍCH TIẾNG VIỆT**

Ý nghĩa của nguyên phân: tạo ra các tế bào con **giống hệt nhau về mặt di truyền**, phục vụ cho **sinh trưởng** (tăng số lượng tế bào), **tái tạo/thay thế** mô bị tổn thương hoặc lão hóa, và **sinh sản vô tính** ở nhiều sinh vật (thực vật nhân giống bằng cành giâm, một số động vật không xương sống sinh sản bằng cách nảy chồi/phân mảnh).

5.5 Control of the cell cycle

Progression through the cell cycle is tightly regulated by internal molecular signals so that DNA replication and division only proceed when conditions are appropriate. Regulatory proteins called **cyclins** rise and fall in concentration at specific points of the cycle; each cyclin binds to and activates a partner enzyme, a **cyclin-dependent kinase (CDK)**. The resulting active cyclin–CDK complex phosphorylates target proteins that drive the cell past a checkpoint into the next phase (for example, a cyclin B–CDK1 complex, sometimes called MPF, triggers entry into mitosis). Three major checkpoints monitor progress:



Cell cycle checkpoints. If DNA damage is detected at the G1 or G2 checkpoint, the cycle is halted while repair enzymes act; if the damage cannot be repaired, the cell may instead undergo apoptosis (programmed cell death), preventing a damaged cell from continuing to divide.

VN **GIẢI THÍCH TIẾNG VIỆT**

Chu kỳ tế bào được kiểm soát bởi các protein **cyclin** (nồng độ tăng giảm theo từng thời điểm) kết hợp với enzyme **CDK (cyclin-dependent kinase)**; phức hợp cyclin–CDK hoạt hóa sẽ "bật đèn xanh" cho tế bào vượt qua điểm kiểm soát để sang pha kế tiếp. Có 3 điểm kiểm soát chính: **G1** (trước khi nhân đôi DNA), **G2** (trước khi vào nguyên phân), và **thoi phân bào** (tại kỳ giữa). Nếu phát hiện DNA hư hỏng, chu kỳ bị tạm dừng để sửa chữa; nếu không sửa chữa được, tế bào có thể tự hủy theo chương trình (**apoptosis**) — đây là cơ chế bảo vệ cơ thể khỏi các tế bào mang đột biến nguy hiểm.

5.6 Cancer: loss of cell cycle control

Cancer arises when mutations disable the normal control of the cell cycle, allowing a cell (and its mitotic descendants) to divide repeatedly and inappropriately, eventually forming a tumour.

Genes controlling cell division

- **Proto-oncogenes** are normal genes whose products (e.g. growth factors, growth factor receptors, signalling proteins) promote cell division when appropriately switched on. A mutation that makes a proto-oncogene permanently active, or overactive, converts it into an **oncogene**, driving excessive cell division even without the normal external signal.

- **Tumour suppressor genes** (e.g. *p53*, *RB*) normally restrain the cycle: their protein products halt the cycle at checkpoints when DNA damage is detected, allowing repair, or trigger apoptosis if damage is too severe to repair. *p53* in particular is often called the "guardian of the genome." Loss-of-function mutations in tumour suppressor genes remove this brake, allowing damaged cells to keep dividing and accumulate further mutations.

Cancer usually requires the accumulation of several such mutations (in proto-oncogenes and/or tumour suppressor genes) within a single cell lineage over time.

A **benign** tumour grows slowly, remains localised, is often surrounded by a capsule of connective tissue, and does not invade surrounding tissue or spread elsewhere in the body. A **malignant** tumour grows more rapidly, invades surrounding tissue, and its cells may break away, travel via the blood or lymphatic system, and establish secondary tumours at distant sites — a process called **metastasis** — making malignant tumours far more dangerous and difficult to treat.

Because cancer cells divide much more rapidly than most normal body cells, many cancer treatments exploit this difference. **Radiotherapy** uses ionising radiation to damage DNA, which disproportionately harms rapidly-dividing cells (which have less time to repair damage before the next division). Many **chemotherapy** drugs work similarly, or specifically interfere with DNA replication or spindle fibre assembly (e.g. spindle poisons, Section 5.4) to block mitosis. Because a few normal cell populations also divide rapidly (e.g. hair follicle cells, the lining of the gut, bone marrow producing blood cells), these treatments commonly cause side effects such as hair loss, nausea, and reduced immunity.

VN **GIẢI THÍCH TIẾNG VIỆT**

Ung thư phát sinh khi các gene kiểm soát chu kỳ tế bào bị đột biến. **Tiền gene sinh ung thư (proto-oncogene)** bình thường thúc đẩy phân bào có kiểm soát; khi bị đột biến trở thành **gene sinh ung thư (oncogene)**, nó luôn "bật" khiến tế bào phân chia không kiểm soát. **Gene ức chế khối u** (như *p53*) bình thường "phanh lại" chu kỳ khi DNA hư hỏng; mất chức năng của các gene này khiến tế bào lỗi vẫn tiếp tục phân chia. **U lành tính** phát triển chậm, khu trú, có vỏ bao, không xâm lấn; **u ác tính** phát triển nhanh, xâm lấn mô xung quanh và có thể **di căn** (metastasis) đến nơi khác qua máu/bạch huyết. Xạ trị và hóa trị khai thác đặc điểm phân chia nhanh của tế bào ung thư để tiêu diệt chúng, nhưng cũng gây tác dụng phụ lên các mô lành phân chia nhanh khác (nang lông, niêm mạc ruột, tủy xương) — giải thích vì sao bệnh nhân hóa trị thường rụng tóc, buồn nôn, suy giảm miễn dịch.

Ví dụ mẫu · Reasoning about p53 loss

Explain, with reference to the normal role of *p53*, why a cell that has lost *both* functional copies of the *p53* gene is at significantly increased risk of becoming cancerous.

Normally, *p53* protein accumulates in response to DNA damage and halts the cycle at the G1 and G2 checkpoints, allowing repair enzymes time to act; if the damage is too extensive to repair, *p53* triggers apoptosis, eliminating the damaged cell altogether. A cell lacking functional *p53* on both homologous chromosomes cannot mount either response: damaged DNA is neither repaired nor does the cell self-destruct. The cell continues dividing, passing on — and potentially accumulating — further mutations (including in proto-oncogenes or other tumour suppressor genes) with each subsequent division, substantially raising the likelihood that a fully cancerous cell line will eventually arise.

5.7 Mitotic index and the root tip squash practical

The rate of cell division in a tissue can be estimated using the **mitotic index**: the proportion of cells, in a sample viewed under a microscope, that are visibly undergoing mitosis at that instant.

$$\text{Mitotic index} = \frac{\text{number of cells showing mitosis}}{\text{total number of cells counted}} \times 100\%$$

A higher mitotic index indicates a greater proportion of cells dividing at any given moment — either because cells are dividing faster, or because a larger fraction of the tissue is actively dividing (e.g. a meristem) rather than in interphase or a resting (G0) state.

A classic practical technique for investigating mitosis is the **root tip squash**: a growing root tip (rich in actively-dividing meristem cells) is cut, and **hydrolysed** briefly in warm dilute hydrochloric acid (typically around 60°C) to soften the tissue by partially breaking down the middle lamella between cells and loosening chromatin, making individual cells easier to separate and stain. The tissue is then **stained** with a DNA-specific stain — commonly **acetic orcein** or **toluidine blue** — which binds strongly to condensed chromosomes, making them clearly visible as dark, distinct bodies against the paler cytoplasm. Finally, the root tip is placed on a slide with a cover slip and gently **squashed** (tapped/pressed) to spread the cells into a single layer, allowing individual cells and their stage of division to be identified and counted under the microscope.

Ví dụ mẫu · Basic mitotic index calculation

A stained root tip squash field of view contains 320 cells, of which 40 show visible chromosomes undergoing mitosis. Calculate the mitotic index.

Mitotic index $= \dfrac{40}{320} \times 100 =$ **12.5**%.

Ví dụ mẫu · Working backwards from a known mitotic index

A tissue sample has a mitotic index of 9%. If 600 cells are counted in total, how many of them are undergoing mitosis?

Number in mitosis $= 9\% \times 600 = 0.09 \times 600 =$ **54** cells.

Ví dụ mẫu · Finding the total cell count

In a separate field of view, 18 cells are observed in mitosis, and the mitotic index is calculated to be 6%. How many cells in total were counted in this field of view?

Rearranging the formula: total cells $= \dfrac{\text{cells in mitosis}}{\text{mitotic index}} = \dfrac{18}{0.06} =$ **300** cells.

Ví dụ mẫu · Estimating the duration of each phase from cell counts

A root tip meristem has a total cell cycle time of 24 hours. A student counts 1000 cells in stained squash preparations and classifies each by stage:

Stage	Interphase	Prophase	Metaphase	Anaphase	Telophase
Cells observed	850	70	30	20	30

(a) Calculate the mitotic index. (b) Estimate the duration of each stage, assuming the proportion of cells observed in a stage is proportional to the fraction of the total cycle time spent in that

stage.

(a) Cells in mitosis $= 70 + 30 + 20 + 30 = 150$. Mitotic index $= \dfrac{150}{1000} \times 100 = \mathbf{15}\%$.

(b) Duration of stage $= \dfrac{\text{cells observed in that stage}}{\text{total cells counted}} \times$ total cycle time:

Stage	Interphase	Prophase	Metaphase	Anaphase	Telophase
Fraction	$850/1000$	$70/1000$	$30/1000$	$20/1000$	$30/1000$
Duration	20.4 h	1.68 h	0.72 h	0.48 h	0.72 h

Check: $20.4+1.68+0.72+0.48+0.72 = 24.0$ h = total cycle time. ✓ Note also that the combined duration of the four mitotic stages, $1.68 + 0.72 + 0.48 + 0.72 = 3.6$ h, equals mitotic index $\times$ cycle time $= 0.15 \times 24 = 3.6$ h, exactly as expected.

VN **GIẢI THÍCH TIẾNG VIỆT**

Chỉ số nguyên phân (mitotic index) = tỉ lệ phần trăm tế bào đang nguyên phân trong tổng số tế bào quan sát. Kỹ thuật **ép đầu rễ (root tip squash)**: cắt đầu rễ đang sinh trưởng (nhiều tế bào mô phân sinh) → **thủy phân** bằng HCl loãng ấm để làm mềm mô (phá vỡ một phần lớp giữa giữa các tế bào) → **nhuộm** bằng thuốc nhuộm đặc hiệu DNA (acetic orcein hoặc toluidine blue) để NST hiện rõ màu đậm → **ép** mẫu trên lam kính để tế bào dàn thành một lớp mỏng, dễ quan sát và đếm dưới kính hiển vi. Vì thời gian một tế bào ở một pha nào đó tỉ lệ với số tế bào quan sát được ở pha đó (trên tổng số tế bào), ta có thể ước tính **thời lượng của từng pha** = (số tế bào ở pha đó / tổng số tế bào) $\times$ tổng thời gian chu kỳ.

5.8 Stem cells and differentiation

A **stem cell** is an undifferentiated cell that can both (i) divide by mitosis to produce more stem cells (self-renewal) and (ii) differentiate into one or more specialised cell types. **Differentiation** is the process by which an unspecialised cell becomes structurally and functionally specialised; because every somatic cell in an organism contains an identical, complete copy of the genome, differentiation is achieved not by losing genes but through **selective (differential) gene expression** — different cell types transcribe and translate different subsets of genes, switching most genes off and only a relevant subset on.

Potency	Can differentiate into...	Example
Totipotent	any cell type of the organism, including extra-embryonic (placental) tissues	the zygote and the cells of the very earliest embryo (up to about the 8-cell stage)
Pluripotent	any of the body's cell types (all three germ layers), but not extra-embryonic tissues	embryonic stem cells (from the inner cell mass of the blastocyst); induced pluripotent stem (iPS) cells reprogrammed from adult body cells
Multipotent	a limited range of related, but not all, cell types	adult/tissue stem cells, e.g. haematopoietic stem cells in bone marrow, which give rise to all types of blood cell
Unipotent	only a single, specific cell type	some adult skin (epidermal) stem cells

Categories of stem cell potency.

Stem cells have significant therapeutic applications: haematopoietic (adult, multipotent) stem cells are already routinely used in bone marrow transplants to treat blood cancers such as leukaemia, and research continues into using pluripotent stem cells to regenerate damaged tissues (e.g. nerve, retinal, or cardiac tissue). The use of **embryonic** stem cells raises ethical considerations because obtaining them typically requires the destruction of an early embryo, which is regulated or restricted in many countries; **induced pluripotent stem (iPS) cells**, reprogrammed directly from adult somatic cells without requiring an embryo, provide an alternative source, although the safety and long-term behaviour of iPS-cell-derived tissue is still an active area of research.

VN **GIẢI THÍCH TIẾNG VIỆT**

Tế bào gốc (stem cell) vừa có khả năng tự nhân đôi (nguyên phân tạo thêm tế bào gốc) vừa có khả năng **biệt hóa** thành các loại tế bào chuyên hóa. Vì mọi tế bào soma đều mang bộ gene giống hệt nhau, sự biệt hóa không phải do mất gene mà do **biểu hiện gene chọn lọc** — mỗi loại tế bào chỉ "bật" một tập hợp gene phù hợp với chức năng của nó. Phân loại theo khả năng biệt hóa: **toàn năng** (totipotent — biệt hóa thành mọi loại tế bào kể cả mô nhau thai, ví dụ hợp tử), **vạn năng** (pluripotent — biệt hóa thành mọi loại tế bào cơ thể nhưng không thành mô nhau thai, ví dụ tế bào gốc phôi), **đa năng** (multipotent — biệt hóa thành một nhóm tế bào liên quan, ví dụ tế bào gốc tạo máu ở tủy xương). Việc sử dụng tế bào gốc phôi gây tranh cãi đạo đức vì phải phá hủy phôi sớm; tế bào gốc vạn năng cảm ứng (iPS) tạo ra từ tế bào trưởng thành là một hướng thay thế.

Ví dụ mẫu · Classifying stem cell potency

A researcher isolates a population of cells from adult bone marrow. In culture, these cells can be shown to give rise to red blood cells, several types of white blood cell, and platelets — but not to nerve cells, muscle cells, or any other unrelated cell type. Classify the potency of these cells and justify your answer.

These cells are **multipotent**: they can differentiate into a limited range of related cell types (in this case, the various components of blood, all deriving from a common haematopoietic lineage), but not into unrelated cell types such as neurons or muscle — ruling out totipotency or pluripotency, which would allow differentiation into any/all body cell types (and, for totipotent cells, extra-embryonic tissue as well).

Ví dụ mẫu · Identifying the stage of mitosis from an observation

A student examines a stained root tip cell under the microscope and describes the following: "the nuclear envelope has already broken down; chromosomes, each clearly consisting of two sister chromatids, are visible scattered throughout the cell but are *not* aligned along a single line; spindle fibres are present." Identify the stage of mitosis shown, giving a reason.

This cell is in **prophase**, not metaphase: although the nuclear envelope has broken down and the spindle has begun to form (both consistent with either late prophase or metaphase), the chromosomes are not yet aligned along the equator (metaphase plate) — they are still scattered. Chromosomes are only found in a single organised row across the cell's equator once metaphase has been reached.

Ví dụ mẫu · Comparing phase durations before and after a treatment

A researcher counts 1000 root tip cells from an untreated control (total cycle time 24 h) and finds 40 cells in metaphase. After treatment with a chemical that partially destabilises spindle fibres, another 1000 cells are counted from a treated sample (cycle time assumed unchanged

at 24 h) and 88 cells are found in metaphase. Estimate the duration of metaphase in each case, and comment on the effect of the treatment.

Control: duration of metaphase $= \dfrac{40}{1000} \times 24$ h $= 0.96$ h (≈ 57.6 min).

Treated: duration of metaphase $= \dfrac{88}{1000} \times 24$ h $= 2.112$ h (≈ 126.7 min).

The treated sample spends roughly twice as long in metaphase as the control. This is consistent with the chemical partially interfering with spindle fibre function: chromosomes take longer to become correctly attached at the metaphase plate, so more cells are ”caught” in metaphase at any instant (and each individual cell takes longer to satisfy the spindle assembly checkpoint) before anaphase can begin.

5.9 Practice

Bài tập luyện tập

Which combination correctly describes the structure of a chromosome as it appears at metaphase of mitosis?

(A) A single DNA molecule with no histone proteins

(B) Two sister chromatids, each one DNA molecule wound around histones, joined at a centromere

(C) A single chromatid attached directly to the nuclear envelope

(D) Two unrelated DNA molecules joined at a telomere

Lời giải chi tiết

By metaphase, DNA has already been replicated (in S phase), so each chromosome consists of two identical sister chromatids (each a DNA molecule wound around histone proteins), joined at the centromere. **(B)**.

Bài tập luyện tập

Explain the function of telomeres, and state what level of DNA packaging directly precedes the fully condensed chromosome seen at mitosis.

Lời giải chi tiết

Telomeres are repetitive, non-coding DNA sequences at each end of a chromosome that protect the coding DNA from loss/degradation during repeated rounds of replication and prevent chromosome ends being mistaken for damaged DNA (which could otherwise trigger inappropriate repair/fusion). The level of packaging immediately preceding the fully condensed mitotic chromosome is the coiled **chromatin fibre** (nucleosomes further looped and supercoiled).

Bài tập luyện tập

Put the following events into the correct order: (i) DNA replication; (ii) cytokinesis; (iii) G1 checkpoint passed; (iv) chromosomes align at the equator; (v) sister chromatids separate.

(A) (iii), (i), (iv), (v), (ii)
(B) (i), (iii), (v), (iv), (ii)
(C) (iii), (iv), (i), (v), (ii)
(D) (ii), (iii), (i), (iv), (v)

Lời giải chi tiết

The correct order is: G1 checkpoint passed (iii) → DNA replication in S phase (i) → chromosomes align at the equator in metaphase (iv) → sister chromatids separate in anaphase (v) → cytokinesis (ii). **(A)**.

Bài tập luyện tập

Why is interphase described as the phase of highest metabolic activity in the cell cycle, despite sometimes being (incorrectly) thought of as a ”resting” phase?

Lời giải chi tiết

During interphase the cell is continuously growing (increasing cytoplasmic volume and protein content), synthesising new organelles, and — during S phase — replicating its entire genome, all of which require substantial ATP expenditure and enzymatic activity. This is far more metabolically demanding than the relatively brief, mechanical process of chromosome movement and division during M phase; interphase is therefore the most metabolically active part of the cycle, not a period of rest.

Bài tập luyện tập

What is the main purpose of the G1 checkpoint?

(A) To check that chromosomes are correctly attached to the spindle
(B) To assess cell size, nutrient availability and DNA integrity before committing the cell to replicate its DNA
(C) To trigger cytokinesis
(D) To reform the nuclear envelope

Lời giải chi tiết

The G1 checkpoint occurs before S phase and checks that conditions (cell size, nutrients, absence of DNA damage) are suitable before the cell commits to the energetically costly process of replicating its entire genome. **(B)**.

Bài tập luyện tập

A cell is treated with a chemical that specifically and completely inhibits DNA polymerase activity, applied right at the start of G1. At what point will the cell cycle stall, and why?

Lời giải chi tiết

The cell will progress normally through G1 (which does not require DNA polymerase) but will stall once it attempts to enter or proceed through **S phase**, since DNA replication (which requires DNA polymerase to synthesise new complementary strands) cannot occur. Without completed, undamaged DNA replication, the cell will also fail the subsequent G2 checkpoint and cannot proceed into mitosis.

Bài tập luyện tập

What specifically triggers the onset of anaphase?

(A) Breakdown of the nuclear envelope

(B) Condensation of chromatin into visible chromosomes

(C) Splitting of each centromere, allowing sister chromatids to separate

(D) Formation of the cleavage furrow

Lời giải chi tiết

Anaphase begins when the centromere holding each pair of sister chromatids splits, allowing the spindle fibres to pull the now-separate chromatids to opposite poles. Nuclear envelope breakdown and chromatin condensation occur earlier, in prophase; the cleavage furrow forms later, during cytokinesis. **(C)**.

Bài tập luyện tập

Describe two differences between cytokinesis in an animal cell and in a plant cell, and explain why these differences occur.

Lời giải chi tiết

In an animal cell, a ring of actin and myosin filaments contracts beneath the plasma membrane, forming a **cleavage furrow** that pinches the cell into two from the outside inward. In a plant cell, Golgi-derived vesicles carrying new cell wall material migrate to the equator and fuse to build a **cell plate**, which grows outward from the centre and matures into a new cross wall, dividing the cell from the inside outward. This difference occurs because plant cells are surrounded by a rigid cellulose **cell wall**, which prevents the plasma membrane from being pinched inward as it can be in an animal cell (which lacks a rigid wall).

Bài tập luyện tập

A diploid somatic cell of a certain organism has a chromosome number of $2n = 8$. State the number of chromosomes and the number of chromatids present in this cell (i) during G1, (ii) during G2, (iii) at metaphase, and (iv) in each daughter cell immediately after telophase.

Lời giải chi tiết

(i) **G1:** DNA has not yet replicated, so there are 8 chromosomes, each consisting of a single chromatid (i.e. 8 chromatids in total).
(ii) **G2:** DNA replication (S phase) has already occurred, so there are still 8 chromosomes, but each now consists of two sister chromatids (16 chromatids in total).
(iii) **Metaphase:** unchanged from G2 — 8 chromosomes, 16 chromatids, now aligned at the equator.
(iv) **Each daughter cell after telophase:** sister chromatids have separated and each is now counted as an individual chromosome, so each daughter cell has 8 chromosomes, each a single chromatid (8 chromatids total per daughter cell) — identical to the original G1 state, as expected for genetically identical daughter cells.

Bài tập luyện tập

Which of the following best explains why mitosis produces genetically identical daughter cells?

(A) Because cytokinesis splits the cytoplasm exactly in half

(B) Because each daughter cell receives one of the two identical sister chromatids of every chromosome, produced by semi-conservative DNA replication in S phase

(C) Because the spindle fibres are identical in every cell

(D) Because mitosis only occurs in cells that already have identical DNA

Lời giải chi tiết

DNA replication in S phase produces two identical sister chromatids for every chromosome; mitosis then ensures that exactly one sister chromatid of each chromosome is delivered to each pole (and therefore to each daughter cell), so both daughter cells receive a complete, identical set of chromosomes. **(B)**.

Bài tập luyện tập

Explain, in terms of cyclins and CDKs, how the cell cycle is driven forward.

Lời giải chi tiết

Regulatory proteins called cyclins rise and fall in concentration at characteristic points of the cell cycle. Each cyclin binds to and activates a specific cyclin-dependent kinase (CDK), forming an active cyclin–CDK complex. This complex phosphorylates target proteins that are needed to drive the cell past a checkpoint and into the next phase of the cycle (for example, a cyclin B–CDK1 complex triggers entry into mitosis). Because different cyclins peak at different times, and each is subsequently degraded, the cycle is driven forward in a controlled, ordered, one-way sequence.

Bài tập luyện tập

What happens to a cell if DNA damage is detected at a checkpoint but the damage is judged too severe to repair?

(A) The cell proceeds to mitosis regardless

(B) The cell undergoes apoptosis (programmed cell death)

(C) The cell immediately becomes cancerous

(D) The checkpoint is skipped and the damage is passed to daughter cells

Lời giải chi tiết

If DNA damage cannot be repaired, checkpoint proteins (such as *p53*) can trigger apoptosis, eliminating the damaged cell before it can divide and pass on its mutations — an important safeguard against the accumulation of cancer-causing mutations. **(B)**.

Bài tập luyện tập

Distinguish between a proto-oncogene and an oncogene.

Lời giải chi tiết

A proto-oncogene is a normal gene whose product (e.g. a growth factor, receptor, or signalling protein) promotes cell division when appropriately activated by external signals. A mutation that makes the gene, or its product, permanently or excessively active converts it into an oncogene, which drives cell division even in the absence of the normal signal, contributing to uncontrolled proliferation.

Bài tập luyện tập

Loss of function of the tumour suppressor gene *p53* is associated with many human cancers. Which statement best explains why?

(A) *p53* normally speeds up the cell cycle, so its loss slows division

(B) *p53* normally halts the cycle and can trigger apoptosis in response to DNA damage; its loss allows damaged cells to keep dividing and accumulating mutations

(C) *p53* is required for cytokinesis, so its loss prevents cell division entirely

(D) *p53* only functions in plant cells

Lời giải chi tiết

p53 is a key tumour suppressor: it halts the cycle at checkpoints when DNA damage is detected (allowing repair) and triggers apoptosis if damage is irreparable. Losing this function allows cells with damaged DNA to continue dividing, accumulating further mutations that can eventually lead to cancer. **(B)**.

Bài tập luyện tập

State two differences between a benign and a malignant tumour.

Lời giải chi tiết

A benign tumour grows relatively slowly, remains localised (often within a capsule of connective tissue), and does not invade surrounding tissue or spread to other parts of the body. A malignant tumour grows more rapidly, invades surrounding tissue, and its cells can break away and travel via the blood or lymphatic system to establish secondary tumours elsewhere in the body (metastasis) — making it far more dangerous.

Bài tập luyện tập

Explain why chemotherapy and radiotherapy commonly cause hair loss and digestive upset as side effects, even though they are intended to target cancer cells.

Lời giải chi tiết

These treatments work by damaging DNA or blocking mitosis (e.g. spindle poisons), which disproportionately affects rapidly-dividing cells since they spend more time in S/M phase and have less opportunity to repair damage before dividing again. Cancer cells divide rapidly and are therefore strongly affected, but a few normal tissues also contain rapidly-dividing cell populations — hair follicle cells and the cells lining the gut (as well as bone marrow) — so these normal tissues are also damaged, producing hair loss and digestive/immune side effects.

Bài tập luyện tập

A microscope field of view from a root tip squash contains 400 cells, of which 52 show condensed, visible chromosomes. Calculate the mitotic index.

(A) 7.7%
(C) 52%
(B) 13%
(D) 1.3%

Lời giải chi tiết

$\frac{52}{400} \times 100 = \mathbf{13\%}$. **(B)**.

Bài tập luyện tập

A tissue sample has a mitotic index of 4%. Out of 750 cells counted in total, how many would you expect to observe undergoing mitosis?

Lời giải chi tiết

Cells in mitosis $= 4\% \times 750 = 0.04 \times 750 =$ **30** cells.

Bài tập luyện tập

In a stained squash preparation, 21 cells are found to be in mitosis, corresponding to a mitotic index of 3.5%. How many total cells were examined in the field of view?

Lời giải chi tiết

Total cells $= \frac{21}{0.035} =$ **600** cells.

Bài tập luyện tập

A researcher compares two root tips: root tip A (untreated control) has a mitotic index of 8%; root tip B (treated with a plant growth hormone) has a mitotic index of 18%, based on equal total cell counts. What does this comparison suggest about the effect of the hormone treatment, and what is one variable that should be kept constant to make this a fair comparison?

Lời giải chi tiết

A higher mitotic index in root tip B suggests that a greater proportion of its cells are undergoing division at any given moment, indicating that the hormone treatment has **increased the rate of cell division** in the root tip meristem compared to the untreated control. For a fair comparison, variables such as temperature, the region of the root sampled (only meristem tissue), the staining/hydrolysis technique and duration, and the age/species of the plant material should be kept constant between the two samples so that hormone treatment is the only variable that differs.

Bài tập luyện tập

A root tip meristem has a total cell cycle time of 18 hours. In 900 counted cells, 54 are in prophase, 18 in metaphase, 12 in anaphase, and 16 in telophase, with the remainder in interphase. Calculate (a) the mitotic index and (b) the estimated duration of anaphase.

Lời giải chi tiết

(a) Cells in mitosis $= 54 + 18 + 12 + 16 = 100$. Mitotic index $= \dfrac{100}{900} \times 100 =$ **11.1**% (to 3 s.f.).

(b) Duration of anaphase $= \dfrac{12}{900} \times 18$ h $= 0.24$ h $\approx$ **14.4** minutes.

Bài tập luyện tập

Explain briefly the purpose of (a) hydrolysing a root tip in warm dilute hydrochloric acid, and (b) staining it with acetic orcein, in the root tip squash technique.

Lời giải chi tiết

(a) Hydrolysis in warm dilute HCl softens the tissue by partially breaking down the middle lamella between cells and loosening chromatin, making it easier to separate individual cells during squashing. (b) Acetic orcein binds strongly and specifically to DNA, staining condensed chromosomes a dark colour so that they are clearly visible against the paler cytoplasm, allowing the stage of mitosis to be identified under the microscope.

Bài tập luyện tập

A drug completely blocks spindle fibre assembly. Predict, with reasoning, what would happen to the appearance of a population of dividing cells treated with this drug over several hours, in terms of the distribution of cells across the stages of the cell cycle.

Lời giải chi tiết

Cells will continue to progress normally through interphase (G1, S, G2) and into prophase, since spindle fibres are not yet required. However, without functional spindle fibres, chromosomes cannot be correctly aligned at, or attached to, the metaphase plate; the spindle assembly checkpoint will detect this and prevent progression to anaphase. Over time, an increasing proportion of dividing cells would therefore accumulate and become ”stuck” at **metaphase**, while the proportion in anaphase, telophase, and (eventually) other stages would fall, and the overall mitotic index would rise as more cells enter but cannot leave metaphase.

Bài tập luyện tập

Which of the following is a totipotent cell?

(A) A haematopoietic stem cell in adult bone marrow

(B) A cell of the very early embryo (up to about the 8-cell stage), capable of forming any cell type including extra-embryonic tissue

(C) An embryonic stem cell from the inner cell mass of a blastocyst

(D) A fully differentiated skin cell

Lời giải chi tiết

Only cells of the very earliest embryo retain the ability to form *every* cell type of the organism, including extra-embryonic (placental) tissues — this defines totipotency. Inner cell mass cells (embryonic stem cells) are pluripotent (all body cell types, but not extra-embryonic tissue); bone marrow stem cells are multipotent; a differentiated skin cell has essentially no remaining potency. **(B)**.

Bài tập luyện tập

Explain how a liver cell and a nerve cell can look and function so differently despite both containing an identical copy of the organism's entire genome.

Lời giải chi tiết

Both cells contain the same complete set of genes, but differentiation occurs through **selective (differential) gene expression**: each cell type transcribes and translates only the subset of genes relevant to its specific structure and function, while the majority of genes are switched off. A liver cell expresses genes for its metabolic enzymes; a nerve cell instead expresses genes for ion channels, neurotransmitter synthesis and long axonal processes. No genes are lost — only the pattern of gene expression differs.

Bài tập luyện tập

State one ethical consideration associated with the use of embryonic stem cells in research and therapy, and describe one alternative source of pluripotent cells that avoids this issue.

Lời giải chi tiết

Obtaining embryonic stem cells typically requires the destruction of an early embryo, which raises ethical concerns regarding the moral status of the embryo and is restricted or regulated in many countries. **Induced pluripotent stem (iPS) cells**, reprogrammed directly from adult somatic cells (e.g. skin cells) without requiring an embryo, provide an alternative source of pluripotent cells that avoids this particular ethical issue, although their long-term safety and behaviour remains an active area of research.

Bài tập luyện tập

Which of the following cell types would you expect to have the *highest* mitotic index under normal conditions?

(A) Mature neurons in the brain
(B) Cells of a root tip meristem
(C) Fully differentiated red blood cells
(D) Cells in G0

Lời giải chi tiết

Root tip meristem cells are actively, continuously dividing to support root growth, so a much higher proportion of them will be captured in mitosis at any instant compared with mature neurons or red blood cells (which have exited the cycle, largely into G0, and rarely or never divide). **(B)**.

Bài tập luyện tập

A cell population has a total cell cycle time of 20 hours and a measured mitotic index of 10%. Estimate the total time this population spends in M phase (mitosis + cytokinesis).

Lời giải chi tiết

Time in M phase $\approx$ mitotic index $\times$ total cycle time $= 0.10 \times 20$ h $=$ **2** hours.

Bài tập luyện tập

Two tissue samples from the same organism are compared: sample X has a cell cycle time of 24 h and mitotic index of 5%; sample Y has a cell cycle time of 12 h and mitotic index of 5%. Which sample has cells spending a longer absolute time in mitosis, and why?

Lời giải chi tiết

Absolute time in mitosis $=$ mitotic index $\times$ total cycle time. For sample X: $0.05 \times 24 = 1.2$ h. For sample Y: $0.05 \times 12 = 0.6$ h. Even though both samples share the same mitotic index, **sample X** spends longer in absolute mitosis time, because the same proportion of a longer total cycle corresponds to a longer absolute duration — this illustrates that mitotic index alone does not tell you the absolute duration of mitosis without also knowing the total cycle time.

Bài tập luyện tập

Outline why asexual reproduction by mitosis produces offspring that are genetically identical to the parent, and give one named example of an organism that reproduces this way.

Lời giải chi tiết

Mitosis produces daughter cells (and, in asexual reproduction, entire offspring) containing an identical copy of every chromosome as the parent cell, because DNA replication in S phase produces two identical sister chromatids for every chromosome, and each daughter cell receives exactly one chromatid (now an independent chromosome) from every pair. No genetic recombination or fusion of gametes occurs, so no new allele combinations are introduced. Example: many plants reproduce asexually via runners or cuttings (e.g. strawberry plants); some invertebrates such as *Hydra* reproduce by budding.

Nucleic Acids and Protein Synthesis

AS Level

Mục tiêu Unit: Cấu trúc nucleotide, DNA và RNA; nguyên tắc bổ sung base và ý nghĩa của số liên kết hydro; ba loại RNA (mRNA, tRNA, rRNA); cơ chế nhân đôi DNA bán bảo toàn (helicase, DNA polymerase, mạch dẫn đầu/mạch ra chậm, DNA ligase) và bằng chứng thực nghiệm Meselson–Stahl; phiên mã và quá trình xử lý pre-mRNA (cắt intron, nối exon); dịch mã tại ribosome; các đặc điểm của mã di truyền và ý nghĩa sinh học; các dạng đột biến gene (thay thế, thêm/mất) và nguyên nhân gây đột biến.

6.1 DNA structure

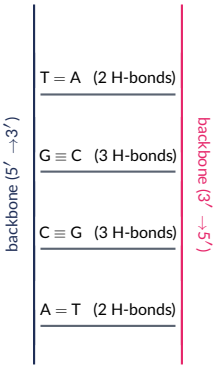
DNA (deoxyribonucleic acid) is a polymer built from repeating monomer units called **nucleotides**. Each DNA nucleotide consists of three parts: a five-carbon sugar (**deoxyribose**), a **phosphate group**, and one of four **nitrogenous bases**. The bases fall into two structural classes: the larger, double-ringed **purines** — adenine (A) and guanine (G) — and the smaller, single-ringed **pyrimidines** — thymine (T) and cytosine (C). Nucleotides are joined into a long strand by **phosphodiester bonds** between the phosphate of one nucleotide and the deoxyribose of the next, forming a sugar–phosphate "backbone" with bases projecting sideways off it.

The DNA double helix

Two DNA strands run **antiparallel** to one another (one strand runs $5' \to 3'$, the other $3' \to 5'$) and twist together into a **double helix**. The strands are held together by hydrogen bonds between **complementary** bases projecting inward from each backbone: a purine always pairs with a pyrimidine, specifically

- **adenine (A) with thymine (T)** — held by **2** hydrogen bonds;
- **cytosine (C) with guanine (G)** — held by **3** hydrogen bonds.

Because a C–G pair has one more hydrogen bond than an A–T pair, **C–G-rich DNA requires more thermal energy to separate (denature)** the two strands than A–T-rich DNA of the same length — C–G-rich DNA is therefore more thermally stable.



A short section of the DNA double helix (shown untwisted, as a "ladder," for clarity): two antiparallel sugar–phosphate backbones connected by complementary base pairs — A–T (2 hydrogen bonds) and C–G (3 hydrogen bonds).

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DNA là polymer gồm các **nucleotide**: đường **deoxyribose** + nhóm **phosphate** + **base nitơ** (A, T, C, hoặc G). Base gồm 2 nhóm: **purine** (vòng đôi: A, G) và **pyrimidine** (vòng đơn: T, C). Hai mạch DNA chạy **đối song song (antiparallel)** — một mạch $5' \to 3'$, mạch kia $3' \to 5'$ — xoắn lại thành **chuỗi xoắn kép**, liên kết với nhau bằng liên kết hydro giữa các base bổ sung: **A–T** (2 liên kết hydro) và **C–G** (3 liên kết hydro). Vì C–G có nhiều liên kết hydro hơn A–T, DNA giàu C–G cần nhiều năng lượng nhiệt hơn để tách hai mạch — do đó **bền nhiệt hơn** DNA giàu A–T.

Ví dụ mẫu · Base composition from a single percentage

A sample of double-stranded DNA contains 34% guanine. Calculate the percentage of the other three bases.

By complementary base pairing, $\%\text{C} = \%\text{G} = 34\%$. The remaining $100 - 34 - 34 = 32\%$ is shared equally between A and T (since $\%\text{A} = \%\text{T}$): $\%\text{A} = \%\text{T} = 32 \div 2 = \mathbf{16}\%$ each.

Ví dụ mẫu · Base composition, a second variation

A different DNA sample is found to be 18% adenine. Calculate the percentage of each of the other three bases.

$\%\text{T} = \%\text{A} = 18\%$. The remaining $100 - 18 - 18 = 64\%$ is shared equally between C and G: $\%\text{C} = \%\text{G} = 64 \div 2 = \mathbf{32}\%$ each.

Ví dụ mẫu · Base counts and total hydrogen bonds

A double-stranded DNA molecule contains $2{,}000{,}000$ nucleotides in total (both strands combined), of which $300{,}000$ are cytosine-containing nucleotides. (a) Calculate the number of adenine-, thymine- and guanine-containing nucleotides. (b) Calculate the total number of hydrogen bonds holding the two strands together.

(a) Since every cytosine on one strand pairs with a guanine on the other, the number of G nucleotides equals the number of C nucleotides: $\text{G} = 300{,}000$. Remaining nucleotides $= 2{,}000{,}000 - 300{,}000 - 300{,}000 = 1{,}400{,}000$, shared equally between A and T: $\text{A} = \text{T} = 700{,}000$ each.

(b) Number of base *pairs* $= 2{,}000{,}000 \div 2 = 1{,}000{,}000$. Of these, $300{,}000$ are C–G pairs (each with 3 H-bonds) and $700{,}000$ are A–T pairs (each with 2 H-bonds):

$$\text{Total H-bonds} = (300{,}000 \times 3) + (700{,}000 \times 2) = 900{,}000 + 1{,}400{,}000 = \mathbf{2{,}300{,}000}.$$

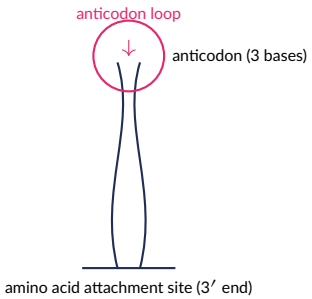
6.2 RNA structure and types

RNA (ribonucleic acid) differs from DNA in three key structural respects: it uses the sugar **ribose** (which has an extra hydroxyl group compared to deoxyribose), the base **uracil (U)** replaces thymine and pairs with adenine, and RNA is normally **single-stranded** rather than forming a double helix, although a single RNA strand can fold back on itself to form local double-stranded regions stabilised by base pairing.

Feature	DNA	RNA
Sugar	Deoxyribose	Ribose
Bases	A, T, C, G	A, U, C, G
Strands	Double-stranded (double helix)	Single-stranded (may fold back on itself)
Typical role	Long-term storage of genetic information	mRNA: carries the genetic message; tRNA: delivers amino acids; rRNA: structural/catalytic component of ribosomes

There are three main types of RNA, each with a distinct role in gene expression:

- **Messenger RNA (mRNA):** a single, linear strand synthesised as a complementary copy of one gene during transcription; it carries the genetic message (as a sequence of codons) from the DNA in the nucleus to ribosomes in the cytoplasm, where it is translated.
- **Transfer RNA (tRNA):** a relatively short RNA molecule that folds into a characteristic **clover-leaf** secondary structure (stabilised by internal base pairing between complementary regions of the same strand). One loop carries a specific triplet, the **anticodon**, which base-pairs with a complementary mRNA codon; the opposite end of the molecule (the $3'$ end) is the site of attachment for the one specific amino acid corresponding to that anticodon.
- **Ribosomal RNA (rRNA):** combines with proteins to form the large and small subunits of the **ribosome**; rRNA is not merely structural but is also **catalytic** — it forms the active site (peptidyl transferase centre) that catalyses peptide bond formation during translation, making the ribosome a ribozyme (an RNA-based enzyme) at its core.



Simplified tRNA structure: a folded, roughly clover-leaf-shaped single RNA strand, with an anticodon loop at one end and the specific amino acid attachment site at the opposite ($3'$) end.

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RNA khác DNA ở 3 điểm: đường **ribose** (thay vì deoxyribose), base **uracil (U)** thay cho thymine, và RNA thường ở dạng **mạch đơn** (có thể gấp lại tạo vùng bắt cặp cục bộ). Ba loại RNA chính: **mRNA** (bản sao thông tin di truyền từ DNA, mang đến ribosome), **tRNA** (cấu trúc "lá cỏ ba lá", mang **bộ ba đối mã (anticodon)** và vị trí gắn một loại amino acid đặc hiệu ở đầu $3'$), **rRNA** (kết hợp với protein tạo nên ribosome; không chỉ có vai trò cấu trúc mà còn có hoạt tính **xúc tác** hình thành liên kết peptide).

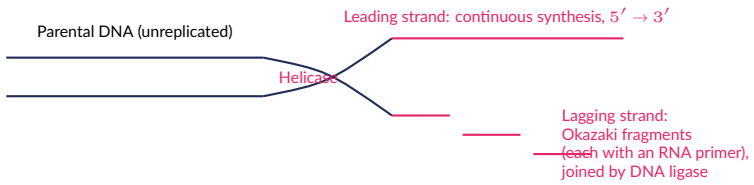
6.3 DNA replication

DNA replication produces two identical DNA molecules from one original molecule, and must occur once (and only once) during S phase of every cell cycle. The enzyme **helicase** unwinds the double helix at a starting point (origin of replication), breaking the hydrogen bonds between base pairs and separating the two parental strands, creating a **replication fork**. Because **DNA polymerase** can only add new nucleotides to the $3'$ **end** of an existing strand — i.e. it synthesises new DNA only in the

$5' \to 3'$ direction, reading the template strand $3' \to 5'$ — and because the two template strands are antiparallel, the two new strands must be synthesised differently at each fork:

Leading and lagging strands

- The **leading strand** is synthesised **continuously** in the $5' \to 3'$ direction, moving in the same direction as the fork opens.
- The **lagging strand** runs in the opposite orientation to the fork's opening direction, so it must be synthesised discontinuously, in short stretches called **Okazaki fragments**, each begun anew (each requiring its own short RNA **primer** to give DNA polymerase a free $3'$ end to extend from, since DNA polymerase cannot start a new strand unaided) and each synthesised $5' \to 3'$ back toward the previous fragment. The enzyme **DNA ligase** subsequently joins (via phosphodiester bonds) the adjacent Okazaki fragments into one continuous new strand.



Semi-conservative DNA replication at the replication fork. Helicase unwinds the double helix; DNA polymerase synthesises new strands $5' \to 3'$ only — continuously on the leading strand, discontinuously (Okazaki fragments) on the lagging strand.

Replication is **semi-conservative**: each of the two resulting DNA molecules consists of one original (parental) strand and one newly synthesised strand, held together as before by complementary base pairing.

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Nhân đôi DNA theo cơ chế **bán bảo toàn**: mỗi phân tử DNA con gồm 1 mạch cũ (từ DNA mẹ) + 1 mạch mới. Enzyme **helicase** tháo xoắn, phá vỡ liên kết hydro giữa hai mạch. Vì DNA polymerase chỉ tổng hợp theo chiều $5' \to 3'$ (chỉ thêm nucleotide vào đầu $3'$ tự do), một mạch (**mạch dẫn đầu — leading**) được tổng hợp **liên tục**, còn mạch kia (**mạch ra chậm — lagging**) được tổng hợp **gián đoạn** thành từng **đoạn Okazaki** ngắn (mỗi đoạn cần một đoạn mồi RNA — primer — để bắt đầu), sau đó được nối lại bởi enzyme **DNA ligase**.

(!) Lỗi thường gặp: Đừng nhầm rằng DNA polymerase có thể tự khởi động một mạch DNA mới từ số 0. Enzyme này chỉ có thể **kéo dài** một mạch đã có sẵn đầu $3'$-OH tự do; vì vậy mỗi điểm bắt đầu tổng hợp (kể cả mạch dẫn đầu, và mỗi đoạn Okazaki trên mạch ra chậm) đều cần một **đoạn mồi RNA (primer)** ngắn do enzyme primase tổng hợp trước.

6.3.1 The Meselson–Stahl experiment

Before 1958, three models had been proposed for how DNA might replicate: **conservative** (the original double helix stays completely intact, and an entirely new double helix is built from scratch), **semi-conservative** (each new molecule has one old strand + one new strand), and **dispersive** (both strands of both new molecules are patchworks of old and new DNA segments). Meselson and Stahl distinguished between these using bacteria (*E. coli*) grown for many generations in a medium containing only the heavy nitrogen isotope ^{15}N, so that all of their DNA became labelled as "heavy." They then transferred the bacteria to normal medium containing only the light isotope ^{14}N, and

sampled DNA after each subsequent round of replication, separating it by density using **caesium chloride density-gradient centrifugation** — molecules of different density (heavy, hybrid, or light) form distinct, separable bands.

Ví dụ mẫu · Predicting density bands, generation by generation

Predict the density band(s) that would be observed after 0, 1 and 2 rounds of replication in ^{14}N medium (starting from fully ^{15}N-labelled DNA), under each of the three proposed models, and state which pattern was actually observed.

Generation 0 (before transfer): all DNA is fully heavy (^{15}N/^{15}N) — a single heavy band, under all three models.

Generation 1:

- *Conservative:* predicts **two** bands — 50% fully heavy (original, intact) and 50% fully light (entirely new molecules).
- *Semi-conservative:* each new molecule is one heavy (old) strand + one light (new) strand — predicts a **single, intermediate (hybrid)** density band.
- *Dispersive:* each strand of each new molecule is an old/new patchwork — also predicts a **single, intermediate** band (indistinguishable from semi-conservative at this stage).

The actual observation after one generation was a **single, intermediate-density band** — this immediately rules out the **conservative** model, which uniquely predicted two separate bands.

Generation 2: starting from the two generation-1 hybrid molecules, each replicates again. Under the **semi-conservative** model, each hybrid molecule yields one hybrid molecule (old heavy strand + new light strand) and one fully light molecule (old light strand + new light strand): of the 4 molecules produced, 2 are hybrid and 2 are fully light — predicting **two** bands (hybrid and light) in a $1:1$ ratio. Under the **dispersive** model, the old and new material would continue to be mixed within both strands of every molecule, predicting a **single** band of intermediate density, only slightly lighter than at generation 1 (never fully resolving into two discrete bands). The actual observation was **two distinct bands** — hybrid and fully light, roughly $1:1$ — ruling out the dispersive model and confirming that DNA replication is **semi-conservative**.

Generation	Total molecules	Hybrid (H/L)	Fully light (L/L)
1	2	2 (100%)	0 (0%)
2	4	2 (50%)	2 (50%)
3	8	2 (25%)	6 (75%)
4	16	2 (12.5%)	14 (87.5%)

Semi-conservative prediction: because only the original two parental strands are ever heavy, exactly 2 hybrid molecules exist at every subsequent generation, while the fraction of fully-light molecules steadily increases.

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Thí nghiệm Meselson–Stahl dùng vi khuẩn *E. coli* nuôi trong môi trường chứa ^{15}N (nặng), sau đó chuyển sang môi trường ^{14}N (nhẹ), rồi ly tâm theo gradient tỉ trọng CsCl để tách DNA theo mật độ. Sau thế hệ 1, chỉ quan sát được **một băng trung gian** (lai nặng-nhẹ) — điều này loại trừ mô hình **bảo toàn (conservative)** (dự đoán 2 băng tách biệt). Sau thế hệ 2, quan sát được **hai băng** (lai và nhẹ hoàn toàn, tỉ lệ 1:1) — điều này loại trừ mô hình **phân tán (dispersive)** (dự đoán vẫn chỉ 1 băng). Kết quả này khẳng định DNA nhân đôi theo cơ chế **bán bảo toàn (semi-conservative)**.

6.4 Transcription

Transcription is the synthesis of an RNA copy of a gene, and takes place in the nucleus (in eukaryotes). **RNA polymerase** binds to a specific DNA sequence, the **promoter**, just upstream of a gene, and unwinds a short section of the double helix. It then moves along the **template (antisense) strand**, reading it in the $3' \to 5'$ direction, and synthesises a complementary, single-stranded **mRNA** molecule in the $5' \to 3'$ direction, using the same A–T/C–G complementary base-pairing rule as replication (except that RNA uses **U** in place of T, so an A on the template strand pairs with a **U** in the new mRNA). The resulting mRNA sequence is therefore identical to the **coding (sense) strand** of the DNA (except that every T is replaced with U), not to the template strand.

In eukaryotes, the initial RNA transcript (**pre-mRNA**) contains both coding regions, **exons**, and non-coding regions, **introns**, interspersed along its length. Before the mRNA leaves the nucleus, a molecular complex called the **spliceosome** removes the introns and joins the remaining exons together — a process called **splicing** — producing the mature mRNA that will be translated. (In many eukaryotic genes, a protective $5'$ cap and a poly-A tail are also added to the ends of the transcript, increasing its stability and aiding export from the nucleus.)

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Phiên mã: RNA polymerase bám vào vùng **promoter**, đọc **mạch khuôn (template/antisense strand)** theo chiều $3' \to 5'$, tổng hợp **mRNA** theo chiều $5' \to 3'$ (dùng U thay T). Trình tự mRNA tạo ra **giống hệt mạch mã hóa (coding/sense strand)** (chỉ khác T→U), **không phải** giống mạch khuôn. Ở sinh vật nhân thực, pre-mRNA còn chứa các đoạn không mã hóa gọi là **intron**; phức hợp **spliceosome** cắt bỏ các intron và nối các đoạn mã hóa (**exon**) lại với nhau (**splicing**) để tạo mRNA trưởng thành trước khi rời khỏi nhân.

(!) Lỗi thường gặp: Đừng nhầm **mạch khuôn (template strand)** với **mạch mã hóa (coding/sense strand)**. RNA polymerase chỉ đọc **mạch khuôn**; mRNA tạo ra có trình tự giống với mạch mã hóa (mạch còn lại, không được đọc trực tiếp) chứ không giống mạch khuôn.

Ví dụ mẫu · Determining an mRNA sequence from a DNA template strand

The template (antisense) strand of a short gene reads, from $3'$ to $5'$: `3'-TAC CGA TGG CTT AAC ATT-5'`. Determine the mRNA sequence transcribed from this template, and state the amino acid sequence it would encode.

Applying complementary base pairing (template → mRNA: T→A, A→U, C→G, G→C) base by base, reading in the same left-to-right order (which is $5' \to 3'$ for the new mRNA, since the template is written $3' \to 5'$):

$$\text{mRNA } (5' \to 3'): \quad \texttt{AUG GCU ACC GAA UUG UAA}$$

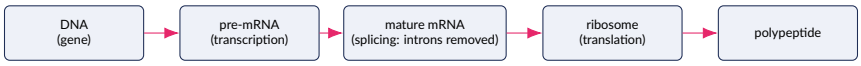
Reading the codons in order: `AUG` (start; Met) → `GCU` (Ala) → `ACC` (Thr) → `GAA` (Glu) → `UUG` (Leu) → `UAA` (stop). The resulting polypeptide is **Met–Ala–Thr–Glu–Leu**, with translation terminating at the stop codon `UAA`.

6.5 Translation

Translation occurs at **ribosomes**, which are formed from a large and a small subunit, each built from rRNA and protein. The small subunit binds mRNA; the large subunit contains three functional binding sites for tRNA: the **A (aminoacyl) site**, where an incoming tRNA carrying the next amino acid first binds; the **P (peptidyl) site**, where the tRNA holding the growing polypeptide chain sits; and the **E (exit) site**, where a spent (deacylated) tRNA sits briefly before leaving the ribosome.

The translation cycle

1. Translation begins at a **start codon**, always **AUG**, which codes for the amino acid **methionine** and sets the **reading frame** for every subsequent codon.
2. A tRNA carrying an anticodon complementary to the current mRNA codon binds at the A site (base-pairing between codon and anticodon, antiparallel).
3. A peptide bond forms between the amino acid held at the A site and the growing polypeptide chain held at the P site (a reaction catalysed by rRNA in the ribosome's peptidyl transferase centre).
4. The ribosome moves (**translocates**) exactly one codon along the mRNA: the tRNA that was at the A site (now carrying the polypeptide) shifts to the P site, the spent tRNA at the P site shifts to the E site and then leaves, and the A site is freed for the next incoming tRNA.
5. This cycle repeats, codon by codon, until a **stop codon** (UAA, UAG or UGA) enters the A site. No tRNA anticodon is complementary to a stop codon, so instead a release factor binds, the completed polypeptide is released, and the ribosomal subunits dissociate from the mRNA.



Overview of gene expression: transcription of DNA into pre-mRNA, removal of introns by splicing to give mature mRNA, and translation at the ribosome into a polypeptide.

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Dịch mã: xảy ra tại ribosome (gồm tiểu đơn vị lớn và nhỏ). Dịch mã bắt đầu tại **codon mở đầu AUG** (mã hóa methionine, xác định khung đọc). Mỗi **tRNA** mang **bộ ba đối mã (anticodon)** bổ sung với codon trên mRNA gắn vào vị trí **A**; liên kết peptide hình thành giữa amino acid mới với chuỗi polypeptide đang được giữ ở vị trí **P**; ribosome sau đó **dịch chuyển (translocation)** đúng một codon dọc theo mRNA, tRNA đã hết amino acid chuyển sang vị trí **E** rồi rời khỏi ribosome. Quá trình lặp lại đến khi gặp **codon kết thúc** (UAA, UAG, hoặc UGA) — không có tRNA nào tương ứng, chuỗi polypeptide được giải phóng.

Ví dụ mẫu · Codon → anticodon and anticodon → codon

(a) An mRNA codon reads $5'$-GAC-$3'$ (which codes for aspartate). State the anticodon on the tRNA that recognises it, with correct polarity. (b) A tRNA anticodon reads $3'$-AAG-$5'$. Determine the mRNA codon it recognises, and the amino acid encoded.

(a) Pairing antiparallel and complementary (A–U, C–G) with codon $5'$-G A C-$3'$: the anticodon is $3'$-C U G-$5'$.

(b) Pairing antiparallel and complementary with anticodon $3'$-A A G-$5'$: codon position 1 ($5'$) pairs with the anticodon's $3'$ base (A, so codon base $=$U); codon position 2 pairs with the anticodon's middle base (A, so codon base $=$U); codon position 3 ($3'$) pairs with the anticodon's $5'$ base (G, so codon base $=$C). The codon is therefore $5'$-UUC-$3'$, which codes for **phenylalanine (Phe)**.

6.6 Properties of the genetic code

The genetic code, by which mRNA codons specify amino acids, has four key properties:

- **Triplet:** each codon consists of exactly three bases. With 4 possible bases, there are $4^3 = 64$ possible codons — more than enough to specify the 20 common amino acids, plus start/stop signals.
- **Degenerate (redundant):** most amino acids are specified by more than one codon (up to six, e.g. leucine and serine). *Significance:* because different codons for the same amino acid often differ only at the third ("wobble") base, many substitution mutations at this position do not change the amino acid produced — degeneracy provides some protection against the effects of point mutations.
- **Non-overlapping:** the code is read in one continuous series of triplets from a fixed starting point, and each base is part of only *one* codon. *Significance:* this is precisely why an insertion or deletion of a number of bases that is *not* a multiple of three shifts the reading frame for every codon downstream, typically scrambling the entire subsequent amino acid sequence (Section 6.7).
- **(Near-)universal:** the same codon almost always specifies the same amino acid in virtually every living organism (a small number of exceptions exist, e.g. in some mitochondrial genomes). *Significance:* this universality is the basis of genetic engineering — a gene (and its codon sequence) from one species can be transferred into, and correctly translated by, a completely different species (e.g. the human insulin gene expressed in bacteria).

Amino acid	Codon(s)	No. of codons
Methionine (start)	AUG	1
Tryptophan	UGG	1
Phenylalanine	UUU, UUC	2
Lysine	AAA, AAG	2
Serine	UCU, UCC, UCA, UCG, AGU, AGC	6
Leucine	UUA, UUG, CUU, CUC, CUA, CUG	6
Stop (no amino acid)	UAA, UAG, UGA	3

A selection of codons from the standard genetic code, illustrating degeneracy: some amino acids (e.g. methionine, tryptophan) have only one codon, while others (e.g. leucine, serine) have as many as six.

VN **GIẢI THÍCH TIẾNG VIỆT**

Mã di truyền có 4 đặc điểm: **bộ ba** (3 base = 1 codon = 1 amino acid, cho $4^3 = 64$ tổ hợp); **thoái hóa (degenerate)** — hầu hết amino acid có nhiều hơn 1 codon, giúp giảm thiểu ảnh hưởng của một số đột biến điểm (đặc biệt ở vị trí base thứ 3); **không chồng lấp (non-overlapping)** — mỗi base chỉ thuộc về 1 codon duy nhất, đọc liên tục theo khung cố định — đây chính là lý do đột biến thêm/mất base (không phải bội số của 3) gây **lệch khung đọc**; và **(gần như) phổ biến (universal)** — hầu như mọi sinh vật đều dùng chung một bộ mã, là cơ sở cho công nghệ kỹ thuật di truyền (chuyển gene giữa các loài).

Ví dụ mẫu · Translating a short mRNA sequence

Translate the mRNA sequence $5'$-`AUG UUU AAA UGG UAG`-$3'$ into its corresponding amino acid sequence.

Reading codon by codon: `AUG` (start, Met) → `UUU` (Phe) → `AAA` (Lys) → `UGG` (Trp) → `UAG` (stop).

The resulting polypeptide is **Met–Phe–Lys–Trp**, with translation terminating at the stop codon `UAG` (which does not code for an amino acid).

6.7 Gene mutations

A **gene mutation** is any change in the nucleotide sequence of DNA. Mutations may be **spontaneous** (rare errors made by DNA polymerase during replication that escape proofreading) or caused by external **mutagens**, including ionising radiation and ultraviolet light (which can break DNA strands or create abnormal covalent links between adjacent bases, e.g. pyrimidine dimers) and certain chemicals (e.g. base-analogue and intercalating agents that disrupt normal base pairing or DNA structure).

Substitution mutations

A **substitution** replaces one base with another, altering exactly one codon. Because of the properties of the genetic code, three outcomes are possible:

- **Silent mutation:** the new codon, due to degeneracy, still codes for the *same* amino acid (common when the change is at the third, "wobble," base) — the protein is unaffected.
- **Missense mutation:** the new codon codes for a *different* amino acid. The effect on the protein ranges from negligible (if the new amino acid has similar chemical properties, or lies away from the functional/active site) to severe (e.g. *sickle-cell* haemoglobin results from a single missense substitution, glutamate → valine, at position 6 of the β-globin chain, which alters the protein's solubility and overall function).
- **Nonsense mutation:** the new codon becomes a *premature stop codon*. Translation halts early, usually producing a severely truncated, non-functional protein.

Insertion and deletion mutations

An **insertion** adds, and a **deletion** removes, one or more nucleotides. If the number of bases added or removed is *not* a multiple of three, every codon downstream of the mutation is regrouped — a **frameshift mutation** — typically producing a completely different, usually non-functional, amino acid sequence from that point onward (and frequently introducing a premature stop codon soon after). Frameshifts are generally far more damaging than substitutions because a substitution alters at most a single amino acid, whereas a frameshift alters essentially the *entire* sequence downstream of the mutation. (An insertion or deletion of exactly three bases, or a multiple of three, adds or removes one or more whole codons without shifting the reading frame — still potentially harmful, but far less disruptive than a true frameshift.)

Mutation type	Effect on sequence	Typical consequence
Substitution (silent)	One base changed; codon still specifies the same amino acid	No change to protein
Substitution (missense)	One base changed; codon specifies a different amino acid	One amino acid changed; effect varies from negligible to severe
Substitution (nonsense)	One base changed; codon becomes a premature stop	Truncated, usually non-functional protein
Insertion/deletion (frameshift)	Number of bases added/removed is not a multiple of 3; all downstream codons regrouped	Entire downstream amino acid sequence altered; usually non-functional protein

Ví dụ mẫu · Tracing a frameshift caused by a single deletion

The original coding (sense) strand of a short gene reads `ATG CAT TCA GGA TAA` (encoding Met–His–Ser–Gly–Stop). Suppose the first `T` of the second codon (`CAT`) is deleted. Write out the new sequence, regroup it into codons, and determine the effect on the encoded polypeptide.

Original: `A T G | C A T | T C A | G G A | T A A` → mRNA `AUG CAU UCA GGA UAA` → Met–His–Ser–Gly–Stop.

After deleting the first T of `CAT`: the sequence becomes `A T G A T T C A G G A T A A` (one base shorter). Regrouping into new triplets from the same starting point:

`ATG | ATT | CAG | GAT | AA…`

mRNA: `AUG AUU CAG GAU AA…` → Met–**Ile**–**Gln**–**Asp**–…— every codon from the point of deletion onward has been regrouped, producing a completely different amino acid sequence (Ile, Gln, Asp…instead of the original His, Ser, Gly, Stop), with no stop codon reached in the segment shown. This illustrates why a single-nucleotide deletion typically has far more drastic consequences than a single-nucleotide substitution.

VN **GIẢI THÍCH TIẾNG VIỆT**

Đột biến gene là sự thay đổi trình tự nucleotide của DNA, có thể do lỗi tự nhiên trong nhân đôi hoặc do **tác nhân gây đột biến** (tia phóng xạ, tia UV, hóa chất). **Đột biến thay thế**: có thể là **câm** (không đổi amino acid, nhờ tính thoái hóa), **sai nghĩa** (đổi 1 amino acid), hoặc **vô nghĩa** (tạo codon dừng sớm, protein bị cắt ngắn). **Đột biến thêm/mất** (không phải bội số của 3) gây **lệch khung đọc (frameshift)** — làm thay đổi toàn bộ trình tự amino acid từ vị trí đột biến trở đi — nghiêm trọng hơn nhiều so với đột biến thay thế, vốn chỉ ảnh hưởng tối đa 1 amino acid.

(!) Lỗi thường gặp: Đừng cho rằng "mọi đột biến gene đều làm thay đổi protein". Đột biến **câm (silent)** không làm thay đổi amino acid (nhờ tính thoái hóa của mã di truyền) nên hoàn toàn không ảnh hưởng đến protein tạo thành — đây là lý do vì sao đột biến thay thế thường ít nguy hiểm hơn nhiều so với đột biến thêm/mất gây lệch khung đọc.

6.8 Practice

Bài tập luyện tập

Which three components make up a single DNA nucleotide?

(A) Ribose, phosphate, and a nitrogenous base

(B) Deoxyribose, a phosphate group, and one of four nitrogenous bases

(C) Two nitrogenous bases and one sugar

(D) A phosphate group and two sugars

Lời giải chi tiết

A DNA nucleotide consists of the sugar deoxyribose, a phosphate group, and one nitrogenous base (A, T, C or G). **(B)**.

Bài tập luyện tập

Distinguish between a purine and a pyrimidine base, and name the two bases in each category.

Lời giải chi tiết

Purines are larger, double-ringed nitrogenous bases: adenine (A) and guanine (G). Pyrimidines are smaller, single-ringed bases: thymine (T) and cytosine (C) (uracil, U, in RNA). In a double helix, a purine always pairs with a pyrimidine (A–T and C–G), keeping the diameter of the helix constant along its length.

Bài tập luyện tập

A sample of double-stranded DNA is found to contain 22% thymine. What percentage of the sample is guanine?

(A) 22%
(B) 28%
(C) 56%
(D) 44%

Lời giải chi tiết

$\%\text{A} = \%\text{T} = 22\%$, so A+T$= 44\%$. The remaining $100 - 44 = 56\%$ is shared equally between C and G: $\%\text{G} = 56 \div 2 =$ **28**$\%$. **(B)**.

Bài tập luyện tập

A double-stranded DNA molecule contains $500{,}000$ base pairs, of which $140{,}000$ are adenine–thymine pairs. Calculate the number of cytosine-containing nucleotides in the molecule.

Lời giải chi tiết

A–T pairs $= 140{,}000$ out of $500{,}000$ total base pairs, so C–G pairs $= 500{,}000 - 140{,}000 = 360{,}000$. Since C and G occur in a $1{:}1$ ratio, the number of cytosine-containing nucleotides equals half of the C–G pairs' nucleotide count: each C–G pair contributes one C nucleotide, so there are **360,000** cytosine-containing nucleotides.

Bài tập luyện tập

Explain, in terms of hydrogen bonding, why a region of DNA rich in cytosine and guanine is more thermally stable (has a higher melting point) than a region rich in adenine and thymine.

Lời giải chi tiết

A cytosine–guanine base pair is held together by three hydrogen bonds, whereas an adenine–thymine pair is held together by only two. More hydrogen bonds means more energy (higher temperature) is required to break them and separate the two strands, so C–G-rich regions of DNA denature (melt) at a higher temperature than A–T-rich regions of the same length.

Bài tập luyện tập

Two DNA strands in a double helix are described as "antiparallel." What does this mean, and why is it significant for DNA polymerase during replication?

Lời giải chi tiết

"Antiparallel" means the two strands run in opposite directions: one strand runs $5' \to 3'$ while its complementary partner runs $3' \to 5'$ alongside it. This is significant because DNA polymerase can only synthesise new DNA in the $5' \to 3'$ direction; since the two template strands point in opposite directions, one new strand (leading) can be made continuously in the same direction as the replication fork opens, while the other (lagging) must be made discontinuously, in short Okazaki fragments, in the opposite direction.

Bài tập luyện tập

Which of the following correctly distinguishes RNA from DNA?

(A) RNA is double-stranded and uses ribose; DNA is single-stranded and uses deoxyribose

(B) RNA uses ribose and uracil and is normally single-stranded; DNA uses deoxyribose and thymine and is double-stranded

(C) RNA and DNA both use the same four bases and are structurally identical

(D) RNA is found only in prokaryotes

Lời giải chi tiết

RNA uses the sugar ribose, uses uracil in place of thymine, and is normally single-stranded; DNA uses deoxyribose, uses thymine, and is normally double-stranded. **(B)**.

Bài tập luyện tập

Describe the structure of a tRNA molecule and explain how this structure allows it to carry out its function in translation.

Lời giải chi tiết

A tRNA molecule is a single RNA strand that folds back on itself, forming a characteristic clover-leaf shape stabilised by internal complementary base pairing. One loop of the folded structure exposes a triplet of unpaired bases, the anticodon, which can base-pair with a complementary codon on mRNA; the opposite ($3'$) end of the molecule is the specific attachment site for the one amino acid corresponding to that anticodon. This dual capability — recognising a specific mRNA codon via the anticodon, while simultaneously carrying the correct corresponding amino acid — allows tRNA to physically link the genetic code (in mRNA) to the correct sequence of amino acids during translation.

Bài tập luyện tập

Which statement about ribosomal RNA (rRNA) is correct?

(A) rRNA has no functional role beyond providing structure to the ribosome

(B) rRNA combines with proteins to form the ribosome and also catalyses peptide bond formation, making the ribosome partly a ribozyme

(C) rRNA carries the anticodon during translation

(D) rRNA is only found in the nucleus, never in the cytoplasm

Lời giải chi tiết

rRNA, together with proteins, forms the large and small ribosomal subunits, and also forms the catalytic peptidyl transferase centre responsible for forming peptide bonds — the ribosome is therefore, at its catalytic core, a ribozyme. **(B)**.

Bài tập luyện tập

Explain why DNA replication is described as semi-conservative, and briefly outline how the Meselson–Stahl experiment provided evidence for this.

Lời giải chi tiết

Semi-conservative replication means each of the two resulting DNA molecules is composed of one original (parental) strand and one newly synthesised strand. Meselson and Stahl grew bacteria in heavy (^{15}N) medium, then transferred them to light (^{14}N) medium and used density-gradient centrifugation to track DNA density over successive generations. After one generation, a single band of intermediate (hybrid) density was observed, ruling out the conservative model (which predicted two separate bands); after two generations, two distinct bands (hybrid and fully light, in a 1:1 ratio) were observed, ruling out the dispersive model (which predicted a single, gradually lightening band). Only the semi-conservative model correctly predicted both results.

Bài tập luyện tập

Which enzyme is responsible for joining adjacent Okazaki fragments on the lagging strand into one continuous strand?

(A) Helicase
(B) DNA polymerase
(C) DNA ligase
(D) RNA polymerase

Lời giải chi tiết

DNA **ligase** catalyses the formation of phosphodiester bonds between adjacent Okazaki fragments, sealing them into a single continuous strand. **(C)**.

Bài tập luyện tập

Why does each Okazaki fragment require its own short RNA primer, while the leading strand needs only a single primer at the very start of replication?

Lời giải chi tiết

DNA polymerase can only extend an existing strand from a free $3'$ end; it cannot begin synthesising a brand-new strand unaided. On the leading strand, synthesis is continuous in the same direction the fork opens, so only one primer is ever needed, at the origin. On the lagging strand, synthesis runs in short bursts away from the fork (because the template runs in the "wrong" direction relative to fork opening), so each new Okazaki fragment must be started afresh, and therefore each requires its own new RNA primer to provide DNA polymerase with a free $3'$ end.

Bài tập luyện tập

A DNA sample is 40% guanine. What percentage of the sample is thymine?

(A) 40%
(B) 20%
(C) 10%
(D) 60%

Lời giải chi tiết

$\%\text{C} = \%\text{G} = 40\%$, so C+G= 80%. The remaining $100 - 80 = 20\%$ is split equally between A and T: $\%\text{T} = 20 \div 2 = \mathbf{10}\%$. **(C)**.

Bài tập luyện tập

State the location and general role of transcription and of translation in a eukaryotic cell.

Lời giải chi tiết

Transcription occurs in the **nucleus**: RNA polymerase copies a gene's template strand into a complementary mRNA molecule (with post-transcriptional splicing removing introns). Translation occurs at **ribosomes** in the cytoplasm (free or bound to the rough endoplasmic reticulum): the mRNA codon sequence is read to assemble a polypeptide chain from amino acids delivered by tRNA.

Bài tập luyện tập

Explain the difference between an intron and an exon, and state what happens to each during the processing of pre-mRNA.

Lời giải chi tiết

Exons are the coding regions of a gene that are retained in the mature mRNA and go on to be translated. Introns are non-coding, intervening sequences found within the initial pre-mRNA transcript. During splicing (carried out by the spliceosome), introns are cut out and degraded, while the exons are joined together to form the continuous, mature mRNA molecule.

Bài tập luyện tập

Which of the following correctly describes the role of the three main tRNA binding sites on a ribosome during translation?

(A) A site: exit of spent tRNA; P site: entry of new tRNA; E site: peptide bond formation

(B) A site: entry of the incoming aminoacyl-tRNA; P site: holds the tRNA bearing the growing polypeptide chain; E site: exit of the deacylated tRNA

(C) A site and P site are identical in function; E site is where mRNA first binds

(D) None of the three sites bind tRNA

Lời giải chi tiết

The A (aminoacyl) site is where the next tRNA, carrying its amino acid, binds; the P (peptidyl) site holds the tRNA attached to the growing polypeptide chain; the E (exit) site is where the spent tRNA sits briefly before leaving the ribosome. **(B)**.

Bài tập luyện tập

Which codon is always the start codon, which amino acid does it code for, and what is its functional significance beyond specifying that amino acid?

Lời giải chi tiết

AUG is the (near-)universal start codon, coding for methionine. Beyond specifying methionine as the first amino acid of a new polypeptide, it establishes the **reading frame** — the fixed grouping of subsequent bases into non-overlapping triplets — for every codon that follows it.

Bài tập luyện tập

An mRNA codon reads 5′-CGA-3′. State the anticodon of the tRNA that would pair with it (with correct polarity), and name the amino acid encoded (arginine is encoded by codons including CGU, CGC, CGA and CGG).

Lời giải chi tiết

Pairing antiparallel and complementary with codon 5′-C G A-3′ (C–G, G–C, A–U): the anticodon is 3′-G C U-5′. The codon CGA codes for **arginine (Arg)**.

Bài tập luyện tập

Explain why the genetic code is described as "non-overlapping," and explain the direct consequence of this property for insertion/deletion mutations.

Lời giải chi tiết

"Non-overlapping" means the mRNA sequence is read as a continuous, uninterrupted series of triplets starting from a fixed point, with each individual base belonging to only one codon (unlike an overlapping code, where a single base could be shared between two adjacent codons). As a direct consequence, if an insertion or deletion changes the number of bases by an amount that is not a multiple of three, every codon from that point onward is regrouped differently — a frameshift — typically scrambling the entire downstream amino acid sequence.

Bài tập luyện tập

Explain why the "degeneracy" of the genetic code can reduce the impact of certain mutations, using an example.

Lời giải chi tiết

Because most amino acids are specified by more than one codon (often differing only at the third, "wobble," base), a substitution mutation at that position may produce a new codon that still specifies the *same* amino acid. For example, both CUU and CUC code for leucine; a substitution changing the third base from U to C would leave the encoded protein completely unchanged — a **silent** mutation, with no effect on phenotype.

Bài tập luyện tập

A single-base substitution changes the codon AAA (lysine) to AAG. Classify this mutation and explain your reasoning (both codons specify lysine).

(A) Nonsense, because a stop codon is created

(B) Silent, because the same amino acid (lysine) is still encoded despite the base change

(C) Missense, because the DNA sequence changed

(D) Frameshift, because one base has changed

Lời giải chi tiết

Both AAA and AAG code for lysine, so despite the base substitution, the encoded amino acid — and therefore the resulting protein — is unchanged. This is a **silent** mutation. It is not a frameshift (only a substitution occurred, not an insertion/deletion), not nonsense (no stop codon was created), and although the term "missense" might tempt you, missense specifically requires a *different* amino acid to be encoded, which did not happen here. **(B)**.

Bài tập luyện tập

The sickle-cell mutation changes a specific codon in the β-globin gene so that glutamate is replaced by valine at one position in the protein. Classify this type of mutation and explain, in general terms, why a missense mutation such as this can (but does not always) significantly affect protein function.

Lời giải chi tiết

This is a **missense** mutation: a single base substitution causes the codon to specify a different amino acid (valine instead of glutamate). Whether a missense mutation significantly affects protein function depends on factors such as whether the new amino acid has similar or very different chemical properties (e.g. charge, polarity, size) to the original, and whether the substituted position lies within a functionally critical region (such as an active site or a region needed for correct folding/interactions). In the sickle-cell case, replacing the negatively-charged glutamate with the non-polar valine changes the surface properties of haemoglobin significantly, leading to abnormal aggregation and the characteristic sickle shape of affected red blood cells.

Bài tập luyện tập

Explain why a nonsense mutation typically has a more severe effect on a protein than a missense mutation occurring at the same position.

Lời giải chi tiết

A missense mutation changes only a single amino acid within an otherwise complete, full-length protein, which may or may not significantly disrupt function. A nonsense mutation instead converts a codon into a premature stop codon, causing translation to terminate early: the protein produced is truncated, typically missing a substantial portion of its normal sequence (including, potentially, functionally essential regions), and is therefore far more likely to be completely non-functional.

Bài tập luyện tập

The coding strand of a gene reads `ATG GTC CAA CGT TAA`. If the second nucleotide of the sequence (a T) is deleted, write the new sequence, regroup it into codons, and briefly state the likely effect on the resulting protein compared with the original.

Lời giải chi tiết

Original coding strand: `ATG GTC CAA CGT TAA` → mRNA `AUG GUC CAA CGU UAA` → Met–Val–Gln–Arg–Stop.
Deleting the second nucleotide (T, in `ATG`) gives: `A G G T C C A A C G T T A A`. Regrouping into new triplets: `AGG | TCC | AAC | GTT | AA...` → mRNA `AGG UCC AAC GUU AA...` → Arg–Ser–Asn–Val...Every codon from the deletion point onward is regrouped, producing a completely different amino acid sequence (and note that the original start codon AUG has itself been destroyed, since the deletion occurred within the very first codon) — this frameshift would almost certainly produce a non-functional protein, in sharp contrast to a single substitution, which would change at most one amino acid.

Bài tập luyện tập

Which of the following changes to a coding sequence would *not* cause a frameshift mutation?

(A) Deletion of one nucleotide

(B) Insertion of one nucleotide

(C) Insertion of three nucleotides (a whole codon)

(D) Deletion of two nucleotides

Lời giải chi tiết

Only a change in the number of nucleotides that is a *multiple of three* preserves the original reading frame for all sequence beyond the mutation (though it does add or remove one or more whole amino acids). Deleting or inserting one or two nucleotides shifts the frame for every subsequent codon. **(C)**.

Bài tập luyện tập

State two possible causes of gene mutation, distinguishing between spontaneous and induced mutations.

Lời giải chi tiết

Spontaneous mutations arise from rare, random errors made by DNA polymerase during replication (mismatched bases that escape proofreading). **Induced** mutations are caused by external mutagens, such as ionising radiation or ultraviolet light (which can break DNA strands or create abnormal bonds between adjacent bases) and certain chemicals (e.g. agents that resemble normal bases and are incorporated incorrectly, or that intercalate between base pairs and distort the DNA structure).

Bài tập luyện tập

Explain why the near-universality of the genetic code is essential to the technique of genetic engineering.

Lời giải chi tiết

Because almost all organisms use the same codon assignments, a gene taken from one species will, in principle, be transcribed and translated correctly by the cellular machinery of a completely different species, producing the same protein. This universality is what allows, for example, a human gene (such as the insulin gene) to be inserted into bacteria, which can then transcribe and translate it correctly to produce a functional human protein.

Bài tập luyện tập

A DNA sample contains $1{,}200{,}000$ total nucleotides, of which $216{,}000$ are guanine. Calculate the number of adenine-, thymine- and cytosine-containing nucleotides.

Lời giải chi tiết

Since G pairs with C, the number of cytosine nucleotides also equals $216{,}000$. Remaining nucleotides $= 1{,}200{,}000 - 216{,}000 - 216{,}000 = 768{,}000$, split equally between A and T: **A** $=$ **T** $=$ **384,000** each.

Bài tập luyện tập

Translate the mRNA sequence $5'$-`AUG GAU AAA UGC UAA`-$3'$ into its amino acid sequence (given: GAU $=$ Asp, AAA $=$ Lys, UGC $=$ Cys).

Lời giải chi tiết

Reading codon by codon: `AUG` (start, Met) $\rightarrow$ `GAU` (Asp) $\rightarrow$ `AAA` (Lys) $\rightarrow$ `UGC` (Cys) $\rightarrow$ `UAA` (stop). The polypeptide produced is **Met–Asp–Lys–Cys**.

Transport in Plants and Mammals

AS Level

Mục tiêu Unit: Vì sao cơ thể lớn cần hệ vận chuyển khối (mass transport); cấu tạo — chức năng của xylem và phloem; các con đường nước đi qua rễ (apoplast, symplast, vacuolar) và vai trò của đai Casparian; thuyết lực kéo–lực dính (cohesion–tension) trong thoát hơi nước; cơ chế đóng/mở khí khổng và các yếu tố ảnh hưởng tốc độ thoát hơi nước; thực hành potometer; thuyết dòng khối (mass/pressure flow) trong vận chuyển phloem; cấu tạo tim và chu kỳ tim; hệ dẫn truyền tự động (myogenic) của tim; cấu tạo — chức năng động mạch/tĩnh mạch/mao mạch; hemoglobin, đường cong phân ly oxy và hiệu ứng Bohr; sự hình thành dịch mô; các yếu tố nguy cơ bệnh tim mạch.

PART A --- TRANSPORT IN PLANTS

7.1 The Need for Mass Transport Systems in Plants

A single cell exchanges gases, water and nutrients directly with its surroundings by diffusion, which is fast enough only over very short distances (diffusion time increases with the *square* of distance, so doubling a distance roughly quadruples the time needed). As an organism increases in size, its **surface area-to-volume (SA:V) ratio** falls, because volume (and therefore metabolic demand) increases with the cube of a linear dimension while surface area increases only with the square. A large multicellular plant, such as a tree tens of metres tall, has:

- a low SA:V ratio, so diffusion across its outer surface cannot supply every internal cell fast enough;
- a high metabolic demand overall (many cells respiring, photosynthesising, growing) but with exchange surfaces (root hairs for water/ions, leaf mesophyll for CO2/O2) often located a great distance from the cells that need those substances (e.g., water absorbed by roots must reach leaves at the top of a tall tree).

Why diffusion alone fails in large plants

Diffusion alone cannot move water, minerals or sugars fast enough over distances of centimetres to many metres. Plants therefore possess two specialised **mass transport (bulk flow) tissues**: **xylem**, which moves water and dissolved mineral ions from root to shoot, and **phloem**, which moves dissolved organic solutes (mainly sucrose) between any **source** and any **sink**. Both rely on bulk (mass) flow of a fluid down a pressure or tension gradient, which is far faster than diffusion over long distances.

VN **GIẢI THÍCH TIẾNG VIỆT**

Khi kích thước cơ thể tăng lên, tỉ lệ diện tích bề mặt trên thể tích (SA:V) giảm dần (vì thể tích tăng theo luỹ thừa 3 trong khi diện tích chỉ tăng theo luỹ thừa 2), khiến khuếch tán đơn thuần không đủ nhanh để cung cấp chất cho toàn bộ tế bào bên trong. Thực vật lớn (đặc biệt là cây thân gỗ) cần hai mô vận chuyển khối chuyên hoá: **xylem** (vận chuyển nước và muối khoáng từ rễ lên) và **phloem** (vận chuyển chất hữu cơ hoà tan, chủ yếu là sucrose, giữa nguồn — source

— và nơi tiêu thụ/dự trữ — sink).

Ví dụ mẫu · Surface area-to-volume ratio and the need for mass transport

Model a small seedling stem as a cube of side 2 mm, and a mature tree trunk as a cube of side 2 m. (a) Calculate the SA:V ratio for each. (b) Comment on the implication for transport.

(a) For a cube of side l: $SA = 6l^2$, $V = l^3$, so $SA : V = 6/l$.
Seedling ($l = 0.2$ cm): $SA : V = 6/0.2 = 30$ cm^{-1}.
Tree trunk ($l = 200$ cm): $SA : V = 6/200 = 0.03$ cm^{-1}.

(b) The tree's SA:V ratio is 1000 times smaller than the seedling's. As a plant grows larger, its outer surface becomes relatively tiny compared with its total volume (and hence its total metabolic demand for water and nutrients), so diffusion across the outer surface alone becomes hopelessly inadequate — confirming the need for xylem and phloem to move substances in bulk (mass flow) directly to and from every internal cell.

7.2 Xylem: Structure and Function

Xylem is a complex tissue whose main water-conducting cells are **xylem vessel elements**. During development, individual vessel elements become specialised then die, leaving behind a hollow, non-living conducting tube:

- the cell **loses its cytoplasm, nucleus and other organelles** at maturity, leaving an empty lumen offering no resistance to water flow;
- the cell wall is thickened and impregnated with **lignin**, a strong, waterproof polymer, deposited in rings, spirals, or as a continuous perforated layer depending on the vessel's age/position; lignification also gives xylem its secondary role of **mechanical support** for the plant body;
- the end walls between adjacent vessel elements break down almost completely, so many vessel elements joined end to end form one long, continuous, unobstructed tube (a xylem vessel) running from root to leaf;
- regions of the wall remain thin and unlignified, forming **pits** — here, water (and dissolved minerals) can move laterally between adjacent vessels, or bypass an air bubble/blockage in one vessel by diverting sideways into a neighbouring one.

Function of xylem: (1) one-way, upward transport of water and dissolved mineral ions from root to stem and leaves; (2) mechanical support of the plant body, since lignified xylem vessels resist collapse even under the negative pressures (tension) generated during transpiration.

VN **GIẢI THÍCH TIẾNG VIỆT**

Mạch gỗ (xylem) là ống dẫn **chết, rỗng**: tế bào mất hết chất nguyên sinh, thành tế bào được tẩm **lignin** (vừa chống thấm nước vừa tạo độ cứng cơ học), và vách ngăn giữa các tế bào liền kề tiêu biến gần như hoàn toàn để tạo thành một ống liên tục từ rễ lên lá. Các vùng thành không hoá gỗ (gọi là **lỗ — pits**) cho phép nước di chuyển ngang sang mạch bên cạnh, ví dụ khi một mạch bị tắc bởi bọt khí (embolism).

7.3 Phloem: Structure and Function

Phloem is a living tissue built from two closely associated cell types working as a functional unit:

- **Sieve tube elements**: living cells joined end to end; at maturity they lose their nucleus and most organelles, and the cytoplasm is reduced to a thin peripheral layer, leaving space for the flow

of **phloem sap**. The end walls between adjacent sieve tube elements are perforated with pores, forming a **sieve plate**, through which sap flows from one element to the next.

- **Companion cells**: one or more small cells lying alongside each sieve tube element, connected to it by numerous **plasmodesmata** (cytoplasmic channels through the cell wall). Companion cells retain a nucleus, ribosomes and unusually many mitochondria, and carry out the metabolic activities (including active transport, requiring ATP) that the enucleate sieve tube element cannot perform for itself.

Function of phloem: translocation — the transport of dissolved organic solutes (mainly sucrose, also amino acids) from a **source** (where they are made or released from storage, e.g. a photosynthesising leaf, or a germinating storage organ) to a **sink** (where they are used or stored, e.g. roots, growing buds, developing fruit or seeds). Unlike xylem, translocation is **not one-directional**: the same stem may carry sap upward and downward in different phloem strands at the same time, depending on where the current sources and sinks are.

Feature	Xylem	Phloem
Cell state	Dead at maturity (no cytoplasm/organelles)	Living (sieve tube element enucleate; companion cell fully living)
Wall	Thickened, lignified	Thin, unlignified (cellulose)
Contents	Water and dissolved mineral ions	Sucrose, amino acids, some hormones/mRNA
End walls	Broken down almost completely (continuous tube)	Perforated sieve plates (pores) between elements
Direction of flow	One-way: roots → leaves	Bidirectional: source → sink (direction depends on plant's needs)
Driving mechanism	Transpiration pull (cohesion–tension); passive	Mass/pressure flow driven by active loading/unloading of sucrose
Associated cells	None (tracheids/fibres for support only)	Companion cells (metabolic support via plasmodesmata)

Table 1. Structural and functional comparison of xylem and phloem.

(!) Lỗi thường gặp: Xylem chỉ vận chuyển **một chiều** (rễ → lá), nhưng phloem vận chuyển **cả hai chiều** tuỳ vị trí source/sink tại từng thời điểm (ví dụ vào mùa xuân, rễ dự trữ trở thành source để nuôi chồi non đang phát triển). Đừng mặc định "phloem luôn đi xuống".

7.4 Water Uptake and Movement Across the Root

Water enters the root through **root hair cells** — epidermal cells with long, thin extensions that greatly increase the surface area in contact with the film of water surrounding soil particles, while also increasing the surface area for active uptake of mineral ions. Water then moves across the root cortex to the xylem in the centre (the stele) by up to three parallel pathways:

Pathway	Route	Speed / notes
Apoplast	Through cell walls and the water-filled spaces between cells; never crosses a plasma membrane	Fastest — walls offer a continuous, low-resistance, freely permeable route
Symplast	Through the cytoplasm, cell to cell, via **plasmodesmata**; crosses the plasma membrane once, on entry into the root hair cell, by osmosis	Slower than apoplast; entire root interior is one continuous cytoplasmic network
Vacuolar	Similar to symplast, but water also passes through the cell vacuoles at each cell	Slowest; often grouped together with the symplast pathway

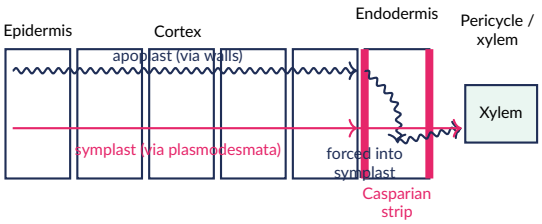

Figure 1. Water pathways across the root cortex. The apoplast route (through cell walls, upper snake path) is blocked at the endodermis by the waterproof **Casparian strip**, forcing water into the symplast (through the plasma membrane and cytoplasm) before it can reach the xylem.

The Casparian strip and endodermal control

The **endodermis** is a single layer of cells surrounding the stele (vascular tissue) of the root. Embedded in the radial and transverse walls of each endodermal cell is a band of **suberin** (a waterproof, fatty substance) called the **Casparian strip**. This strip completely blocks the apoplast pathway at the endodermis: water and any dissolved ions travelling via the cell walls cannot pass through the strip, and must instead cross a plasma membrane and continue via the symplast. This forces *all* water and mineral ions to pass through at least one selectively permeable membrane before entering the stele, allowing the plant to actively control and select which mineral ions are allowed into the xylem (via specific membrane transport proteins), rather than ions diffusing in uncontrolled through the cell walls.

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Đai Casparian là một dải chất suberin không thấm nước nằm trong thành tế bào nội bì (endodermis), chặn hoàn toàn con đường apoplast tại vị trí này. Do đó nước (và ion khoáng) buộc phải đi qua màng sinh chất (con đường symplast) để vào trụ mạch (stele) — nhờ vậy cây có thể **chọn lọc** loại ion khoáng nào được phép đi vào mạch gỗ, thay vì để ion khuếch tán tự do không kiểm soát qua thành tế bào.

Ví dụ mẫu · Reasoning through a Casparian-strip mutant

A mutant plant is unable to deposit suberin, so its endodermal cells lack a functional Casparian strip. Predict what would happen to the plant's ability to control the mineral ion composition of its xylem sap, and explain your reasoning.

Without the Casparian strip, the apoplast pathway would remain open (unblocked) all the way from the soil, through the cortex, and directly into the stele/xylem. Water and dissolved mineral ions would therefore be able to diffuse straight into the xylem through the cell walls alone, **without ever crossing a selectively permeable plasma membrane**. This would remove the plant's ability to actively select which mineral ions (and in what quantities) enter the xylem, since selective membrane transport proteins would simply be bypassed — the mutant plant would lose fine control over its xylem sap composition, potentially taking up toxic ions or losing beneficial ones that would normally be excluded or concentrated by the endodermis.

7.5 Transpiration and the Cohesion--Tension Theory

Transpiration is the evaporation of water from the aerial parts of a plant (mainly through open stomata in the leaves) into the atmosphere. It is essentially an unavoidable side effect of gas exchange: stomata must open to allow CO2 in for photosynthesis, and because the air spaces inside the leaf are saturated with water vapour while the outside atmosphere usually is not, water vapour diffuses out down its water potential/concentration gradient whenever stomata are open.

The cohesion–tension theory, step by step

1. Water evaporates from the moist cell walls of mesophyll cells into the sub-stomatal air spaces, then diffuses out of the leaf through open stomata (transpiration).
2. This lowers the water potential of the mesophyll cells nearest the air spaces, so water moves into them by osmosis from neighbouring cells, and ultimately from the xylem in the leaf veins.
3. As water is drawn out of the leaf xylem, this generates a **tension** (a negative pressure) that is transmitted down the entire, continuous water column in the xylem vessel, all the way from leaf to root.
4. Water molecules are held to one another by **cohesion** (hydrogen bonding between adjacent water molecules), which keeps the water column continuous and unbroken, allowing the tension to be transmitted as a pull along its whole length rather than the column simply snapping.
5. Water molecules also **adhere** to the cellulose/lignin of the xylem vessel walls, which helps support the column against gravity and against the walls of the narrow vessel.
6. The resulting **transpiration pull** draws water (with dissolved mineral ions) continuously upward from the roots, and ultimately draws more water into the root hair cells from the soil by osmosis, replacing what was lost.

Cohesion–tension is a **passive** physical process: the driving force (evaporation at the leaf) requires no metabolic energy from the plant itself for the bulk movement of water up the xylem — solar energy evaporates the water. This is why cut, dead (but still hydraulically intact) stems can still draw up water and dye solutions.

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Thuyết lực kéo–lực dính (cohesion–tension): nước bốc hơi qua khí khổng ở lá (thoát hơi nước) tạo ra một lực kéo (tension) truyền xuống toàn bộ **cột nước liên tục** trong mạch gỗ. Các phân tử nước **dính vào nhau** (cohesion, nhờ liên kết hydro) giữ cho cột nước không bị đứt gãy, đồng thời **dính vào thành mạch** (adhesion) giúp chống lại trọng lực. Đây là quá trình **thụ động**, không cần năng lượng trao đổi chất trực tiếp — năng lượng đến từ ánh sáng mặt trời làm bốc hơi nước ở lá.

7.6 Stomata, Guard Cells and Factors Affecting Transpiration Rate

7.6.1 The guard cell mechanism

Each stoma (pore) is flanked by a pair of **guard cells**, whose changing shape opens or closes the pore.

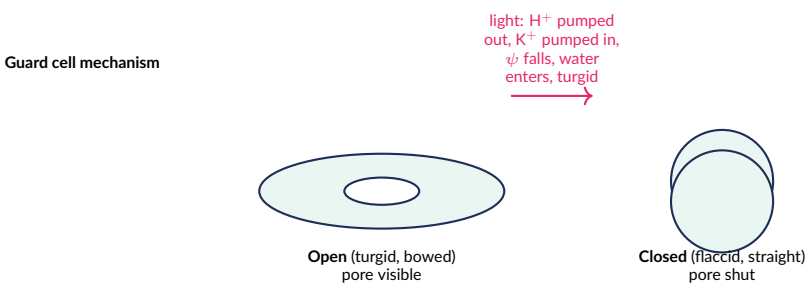


Figure 2. Guard cell shape change. The wall bordering the pore is thicker/less elastic than the outer wall, so a turgid guard cell bows into a crescent, opening the pore; a flaccid guard cell straightens, closing it.

Opening and closing

Opening (light): guard cells actively pump H+ ions out across the plasma membrane (using ATP-driven proton pumps). The resulting electrochemical gradient drives K+ ions into the guard cell through voltage-gated potassium channels (Cl− and organic acids such as malate also accumulate). This lowers the guard cell's water potential, so water enters by **osmosis** from neighbouring epidermal cells, and the guard cells become **turgid**. Because the inner wall (bordering the pore) is thicker and less elastic than the outer wall, the whole cell bows outward into a curved shape as it swells, pulling the pore open.

Closing (darkness / water stress): K+ (and associated ions) are actively pumped back out of the guard cells — often triggered by the plant hormone **abscisic acid (ABA)** under drought stress. Water potential rises, water leaves by osmosis, the guard cells become **flaccid**, straighten, and the pore closes, reducing further water loss.

VN **GIẢI THÍCH TIẾNG VIỆT**

Khi có ánh sáng, tế bào bảo vệ (guard cell) chủ động bơm H+ ra ngoài, kéo theo dòng K+ đi vào tế bào, làm giảm thế nước (ψ) bên trong; nước đi vào bằng thẩm thấu khiến tế bào **trương nước (turgid)**. Vì thành tế bào phía trong (giáp lỗ khí) dày hơn thành phía ngoài, tế bào cong lại và mở lỗ khí. Khi thiếu ánh sáng hoặc thiếu nước (nhờ hormone **ABA**), K+ bị bơm ra ngoài, tế bào mất nước, trở nên mềm (flaccid) và lỗ khí đóng lại.

7.6.2 Environmental factors affecting the rate of transpiration

Factor	Effect	Reason
Light intensity	↑ light ⇒ ↑ rate	More stomata open wider (needed for CO2 uptake for photosynthesis), increasing the area available for water vapour to diffuse out.
Temperature	↑ temperature ⇒ ↑ rate	More kinetic energy speeds evaporation from mesophyll cell walls; warmer air can also hold more water vapour, steepening the water potential gradient out of the leaf.
Humidity	↑ humidity ⇒ ↓ rate	A more humid atmosphere has a higher water vapour concentration, reducing the concentration/water-potential gradient between the (saturated) leaf air spaces and the air, slowing net diffusion out.
Wind speed	↑ wind ⇒ ↑ rate	Moving air sweeps away the humid layer of air that builds up next to a still leaf surface, maintaining a steep concentration gradient and so a faster rate of diffusion out through the stomata.

Table 2. Environmental factors and their effect on transpiration rate.

Ví dụ mẫu · Interpreting transpiration data under different conditions

A potometer records the following distances moved by the air bubble in 5 minutes, on the same shoot, under different conditions (tube radius constant):

Condition	Still air, dim light	Fan blowing, dim light	Fan blowing, bright light
Distance moved (cm)	4	10	16

Explain the pattern.

Reasoning: moving from still air to moving air (fan) more than doubles the distance (4 cm → 10 cm) because the fan continually removes the humid boundary layer around the leaf, maintain-

ing a steep water-potential gradient for diffusion out of the stomata. Adding bright light on top of the fan further increases the rate (10 cm → 16 cm) because light causes stomata to open wider (more CO2 needed for photosynthesis), increasing the total pore area available for water loss. The two factors act independently and combine to produce the highest transpiration rate when both act together.

(!) Lỗi thường gặp: Độ ẩm **cao** làm **giảm** tốc độ thoát hơi nước (vì làm giảm chênh lệch thế nước giữa bên trong lá và không khí), chứ không phải làm tăng. Đừng nhầm lẫn "độ ẩm cao" với "nhiều nước hơn để thoát ra".

Ví dụ mẫu · Effect of temperature on transpiration rate

A potometer bubble moves 6 cm in 5 minutes at $15\,^{\circ}$C, and 18 cm in 5 minutes (same shoot, same tube) at $30\,^{\circ}$C, all other conditions held constant. (a) Calculate the factor by which the rate has increased. (b) Explain this increase in terms of the underlying physical process.

(a) Rate at $15\,^{\circ}$C: $6/5 = 1.2$ cm/min (in the units of distance moved; volume scales identically since tube radius is unchanged, so the ratio of rates equals the ratio of distances). Rate at $30\,^{\circ}$C: $18/5 = 3.6$ cm/min. Factor increase $= 3.6/1.2 =$ **3.0**-fold.

(b) Raising temperature from $15\,^{\circ}$C to $30\,^{\circ}$C increases the kinetic energy of water molecules, speeding evaporation from the mesophyll cell walls into the leaf air spaces. Warmer air can also hold more water vapour, which (combined with faster evaporation) steepens the water-potential/concentration gradient driving diffusion of water vapour out of the stomata — together tripling the rate of transpiration (and hence water uptake) over this $15\,^{\circ}$C rise.

7.7 Measuring Transpiration: The Potometer

A **potometer** measures the rate of water **uptake** by a cut, leafy shoot, which is used as a close estimate of the rate of transpiration (since well over 99% of water taken up by a shoot is lost by transpiration; only a very small fraction is retained for photosynthesis, growth, or cell turgor).

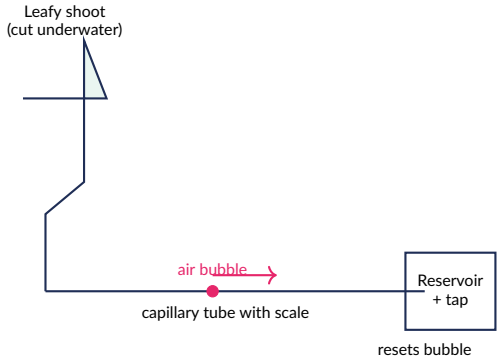


Figure 3. A simple bubble potometer: a leafy shoot is connected (via rubber tubing, airtight) to a horizontal capillary tube marked with a scale. An air bubble introduced into the tube moves as water is drawn up by the shoot; the reservoir tap resets the bubble to the start of the scale between readings.

Method: cut a leafy shoot underwater (at a slant, to increase the cut surface and prevent air entering the xylem) and assemble the whole apparatus underwater so that no air enters the system. Introduce a single air bubble into the capillary tube (by briefly lifting its end out of water), record its starting position, then time how long it takes to move a measured distance (or measure the distance moved in a fixed time). Calculate the volume of water taken up using the volume of a cylinder, $V = \pi r^2 h$, where h is the distance moved by the bubble and r is the internal radius of the capillary tube. Repeat under different environmental conditions (varying one factor at a time — light, humidity, wind, temperature), resetting the bubble with the reservoir tap between readings, and take replicate readings to calculate a mean.

Sources of error: the potometer measures water *uptake*, not transpiration directly (a very small proportion of the water taken up is used in photosynthesis or retained by growing cells, so uptake very slightly overestimates transpiration); air may leak into the joints; the shoot needs time to acclimatise after cutting; if comparing different shoots, differences in leaf area/number must be controlled (best practice is to use the *same* shoot throughout and vary only the environmental factor being tested).

Ví dụ mẫu · Potometer calculation (1)

An air bubble moves 12 cm along a capillary tube of internal radius 0.05 cm in 5 minutes. Calculate the rate of water uptake.

$V = \pi r^2 h = \pi(0.05)^2(12) = \pi(0.0025)(12) = 0.0942$ cm^3.

Rate $= \dfrac{0.0942 \text{ cm}^3}{5 \text{ min}} \approx$ **0.0188** cm^3/min.

Ví dụ mẫu · Potometer calculation (2)

In a repeat trial with a fan blowing air across the leaves, the same tube (radius 0.05 cm) shows the bubble moving 9.5 cm in just 2 minutes. (a) Calculate the new rate of water uptake. (b) Compare it with the still-air rate from the example above and explain the difference.

(a) $V = \pi(0.05)^2(9.5) = \pi(0.0025)(9.5) = 0.0746$ cm^3. Rate $= \dfrac{0.0746}{2} \approx$ **0.0373** cm^3/min.

(b) 0.0373 cm^3/min is roughly double the still-air rate of 0.0188 cm^3/min. Moving air removes the humid boundary layer that builds up around the leaf surface in still air, maintaining a steeper water-potential/concentration gradient between the leaf air spaces and the atmosphere, and so increasing the rate of diffusion of water vapour out through the stomata (and, correspondingly, the rate of water uptake by the xylem).

7.8 Translocation: The Mass Flow (Pressure Flow) Hypothesis

Mass flow hypothesis, step by step

1. **At the source** (e.g. a photosynthesising leaf): companion cells actively transport sucrose into the sieve tube elements (active loading, using ATP — typically a proton pump creates an H+ gradient that drives sucrose in via a co-transporter). This lowers the water potential inside the sieve tube at the source.
2. Water therefore enters the sieve tube from the adjacent xylem by **osmosis**, raising the **hydrostatic (turgor) pressure** inside the sieve tube at the source end.
3. **At the sink** (e.g. a root, growing bud, or developing fruit): sucrose is removed from the sieve

tube — used in respiration, converted to starch for storage, or built into new cell material — raising the water potential inside the sieve tube at the sink.

4. Water therefore leaves the sieve tube by osmosis into the surrounding cells/xylem at the sink, lowering the hydrostatic pressure there.
5. The resulting **pressure difference** (high at the source, low at the sink) drives a passive **mass flow** of the whole phloem sap solution through the sieve tubes, via the pores of the sieve plates, from source to sink — carrying the dissolved sucrose along with the flowing water.

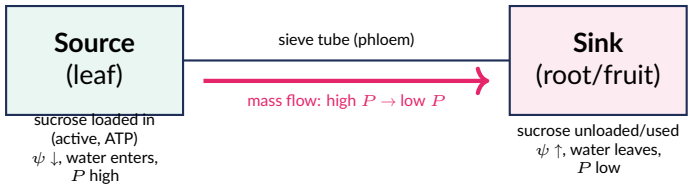


Figure 4. The mass flow (pressure flow) hypothesis: active loading/unloading of sucrose at source/sink drives osmotic water movement, generating a hydrostatic pressure gradient that pushes phloem sap from source to sink.

Ví dụ mẫu · Water potential reasoning in translocation

At the source end of a sieve tube, the solute potential is $\psi_s = -1400$ kPa and the pressure potential is $\psi_p = +700$ kPa. At the sink end (after unloading), $\psi_s = -300$ kPa and $\psi_p = +150$ kPa. (Recall $\psi = \psi_s + \psi_p$.) (a) Calculate the overall water potential at each end. (b) Between the sieve tube and the surrounding xylem/cells (assume $\psi_{\text{xylem}} \approx -50$ kPa throughout), predict the direction water moves at the source and at the sink, and explain how this creates the pressure gradient driving mass flow.

(a) Source: $\psi = -1400 + 700 = -700$ kPa. Sink: $\psi = -300 + 150 = -150$ kPa.

(b) At the source, $\psi_{\text{sieve tube}} = -700$ kPa is far more negative than $\psi_{\text{xylem}} \approx -50$ kPa, so water moves *into* the sieve tube from the xylem by osmosis, raising its hydrostatic pressure. At the sink, $\psi_{\text{sieve tube}} = -150$ kPa is still slightly more negative than -50 kPa but far less negative than at the source, so proportionally much less water is drawn in (and, as sucrose continues to be removed, water potential there rises further and water tends to leave into the surrounding tissue). The much higher pressure generated at the source than at the sink is exactly the pressure gradient ($P_{\text{source}} > P_{\text{sink}}$) that drives the mass flow of sap along the sieve tube.

Evidence supporting mass flow: sap exudes under high pressure when a sieve tube is cut (e.g. using an aphid's stylet as a natural "probe" — sap continues to flow from a severed stylet for hours, showing the tube is under real hydrostatic pressure); sucrose concentration is measurably higher in sieve tubes near a source than near a sink; ringing (removing a strip of bark/phloem) causes swelling above the cut as sugars accumulate, exactly as predicted.

Evidence/observations not fully explained by mass flow: sieve plates should offer considerable resistance to flow, yet measured flow rates are faster than a simple calculation (based on sieve pore dimensions) would predict; different solutes in the same sieve tube have sometimes been observed to move at different speeds simultaneously, which pure mass (bulk) flow of a single solution struggles to explain; the mechanism depends on living, metabolically active companion cells (active loading/unloading, ATP-dependent), so it is not a purely passive physical process throughout.

VN **GIẢI THÍCH TIẾNG VIỆT**

Thuyết dòng khối (mass/pressure flow): tại **source**, sucrose được vận chuyển chủ động vào ống rây (tốn ATP), làm giảm thế nước, nước theo đó đi vào bằng thẩm thấu, làm tăng áp suất; tại **sink**, sucrose bị lấy ra/sử dụng, thế nước tăng, nước theo đó ra ngoài, làm giảm áp suất. Chênh lệch áp suất giữa hai đầu (*cao ở source, thấp ở sink*) đẩy toàn bộ dòng dịch phloem chảy theo dạng **dòng khối (bulk flow)** từ source đến sink, mang theo cả sucrose hoà tan.

(!) Lỗi thường gặp: "Phloem luôn vận chuyển đường từ lá xuống rễ" — sai. Hướng vận chuyển phụ thuộc vào vị trí source/sink **tại thời điểm đó**, không cố định theo giải phẫu. Ví dụ củ khoai tây dự trữ (sink vào mùa thu) có thể trở thành source vào mùa xuân khi nuôi chồi mọc lên.

PART B --- TRANSPORT IN MAMMALS

7.9 The Need for a Mass Transport System in Mammals

Like large plants, large active mammals have a low SA:V ratio and a very high metabolic demand (endothermic, active) — diffusion alone cannot deliver O2, nutrients and hormones (or remove CO2 and waste) fast enough over the distances involved. Mammals therefore have a closed, **double circulatory system**: blood is confined to vessels (closed) and passes through the heart **twice** for every one complete circuit of the body.

Why double, not single, circulation?

In a single circulatory system (e.g. fish), blood passes through only one capillary bed (the gills) per circuit before travelling on to the rest of the body; the narrow capillaries of the gills cause a large drop in blood pressure, so blood reaches the body tissues slowly and at low pressure. In a mammal's **double circulation**, blood returning from the lungs (where pressure has dropped, having passed through the pulmonary capillaries) is sent back through the heart and **re-pressurised** before being pumped out around the body (systemic circuit). This maintains a high blood pressure and rapid, efficient delivery of oxygenated blood to metabolically active tissues.

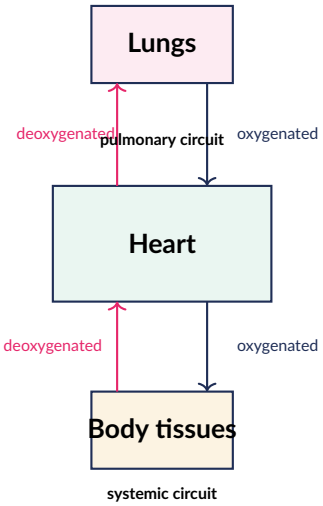


Figure 5. Double circulation: blood passes through the heart twice per full circuit — once via the pulmonary circuit (heart ↔ lungs) and once via the systemic circuit (heart ↔ body) — allowing it to be re-pressurised between the two.

VN **GIẢI THÍCH TIẾNG VIỆT**

Vì cơ thể động vật có vú lớn, hoạt động mạnh và tỉ lệ SA:V thấp, khuếch tán đơn thuần không đủ nhanh — cần một hệ tuần hoàn khối **kép (double circulation)**: máu đi qua tim **hai lần** mỗi vòng tuần hoàn hoàn chỉnh (một vòng phổi, một vòng cơ thể), giúp máu được **tăng áp lại** sau khi đi qua mao mạch phổi (nơi áp suất giảm mạnh), nhờ đó máu vẫn được bơm đến các mô với áp suất cao và tốc độ nhanh.

7.10 Heart Structure

The mammalian heart has **four chambers**: two thin-walled **atria** (upper, receiving chambers) and two thick-walled, muscular **ventricles** (lower, pumping chambers). A muscular **septum** separates the left and right sides completely, preventing oxygenated and deoxygenated blood from mixing.

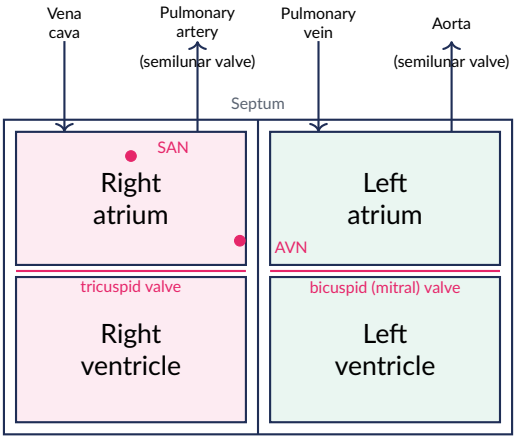


Figure 6. The mammalian heart, drawn conventionally (the patient's right side appears on the reader's left). Deoxygenated blood: vena cava → right atrium → (tricuspid valve) → right ventricle → (pulmonary semilunar valve) → pulmonary artery → lungs. Oxygenated blood returns: pulmonary vein → left atrium → (bicuspid/mitral valve) → left ventricle → (aortic semilunar valve) → aorta → body.

Valves ensure blood flows in one direction only: **atrioventricular (AV) valves** — the **tricuspid** (right) and **bicuspid/mitral** (left) — sit between atrium and ventricle, anchored by tendinous cords (chordae tendineae) to papillary muscles, preventing the valve flaps being forced back into the atria when the ventricles contract. **Semilunar valves** sit at the base of the pulmonary artery and the aorta, preventing blood flowing back into the ventricles once ejected. All heart valves are one-way and open/close purely in response to **pressure differences** on either side, not by active muscular effort of the valve itself.

The **left ventricle wall is much thicker/more muscular** than the right, because the left ventricle must generate sufficient pressure to pump blood around the entire **systemic** circuit (a long, high-resistance path to every organ in the body), whereas the right ventricle only pumps blood a short distance to the nearby lungs (pulmonary circuit, lower resistance, lower pressure required).

VN **GIẢI THÍCH TIẾNG VIỆT**

Tim có 4 ngăn: 2 tâm nhĩ (thành mỏng, nhận máu) và 2 tâm thất (thành dày, bơm máu đi xa). Vách ngăn (septum) ngăn máu giàu oxy và máu nghèo oxy trộn lẫn. Van tim (van nhĩ-thất và van bán nguyệt) chỉ cho máu chảy **một chiều**, đóng/mở hoàn toàn do **chênh lệch áp suất**, không phải do co cơ chủ động của van. Thành tâm thất trái dày hơn tâm thất phải nhiều vì phải tạo đủ áp lực bơm máu đi khắp cơ thể (vòng tuần hoàn hệ thống dài, trở kháng cao), trong khi tâm thất phải chỉ bơm máu một quãng ngắn đến phổi.

7.11 The Cardiac Cycle

The **cardiac cycle** is the sequence of events in one heartbeat, alternating **systole** (contraction) and **diastole** (relaxation):

1. **Diastole (general):** both atria and ventricles are relaxed; blood flows passively from the veins into the atria and on into the ventricles through the open AV valves (semilunar valves remain closed, since arterial pressure exceeds ventricular pressure at this point).
2. **Atrial systole:** the atria contract, pushing the last of the blood into the (nearly full) ventricles.
3. **Ventricular systole:** the ventricles contract; ventricular pressure rises rapidly and quickly exceeds atrial pressure, forcing the AV valves shut — this produces the first heart sound (**"lub"**). As ventricular pressure continues to rise and exceeds the pressure in the aorta/pulmonary artery, the semilunar valves are forced open and blood is ejected into the arteries.
4. **Ventricular diastole:** the ventricles relax; ventricular pressure falls below arterial pressure, and the resulting slight backflow of blood forces the semilunar valves shut — this produces the second heart sound (**"dub"**). As ventricular pressure continues to fall below atrial pressure, the AV valves reopen and the cycle repeats.

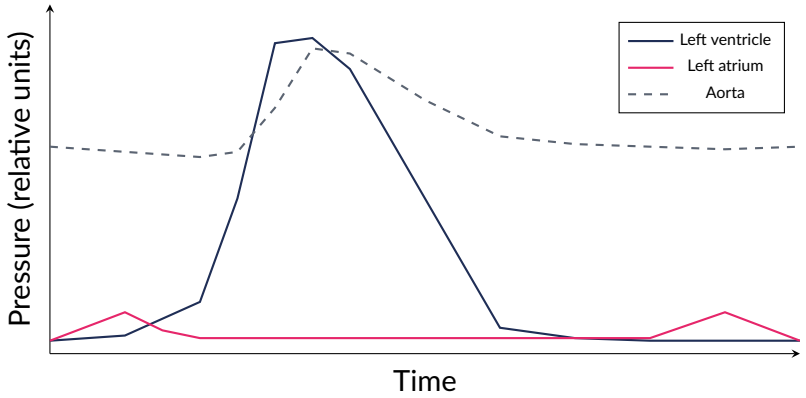


Figure 7. Simplified pressure-time relationships in the left side of the heart. AV valves close when ventricular pressure first exceeds atrial pressure (start of the sharp ventricular rise); the aortic (semilunar) valve opens when ventricular pressure exceeds aortic pressure, and closes again when ventricular pressure falls back below it.

Ví dụ mẫu · Reading the cardiac cycle graph

Using Figure 7, at approximately what point does the aortic semilunar valve open, and what does the small early rise in atrial pressure (just before the sharp ventricular rise) represent?

The aortic valve opens once ventricular pressure rises above aortic pressure — on the graph, this is where the steeply rising ventricular curve crosses above the aortic curve (around the point ventricular pressure reaches roughly 95–100 units, just before its peak). The small early rise in atrial pressure represents **atrial systole**: the atria contracting to push the final volume of blood into the ventricles just before ventricular systole begins.

7.12 Myogenic Stimulation and the Conduction System

The heart is myogenic

The heart initiates its own rhythmic contractions — it is **myogenic** — and does not require an external nerve impulse to beat (though the autonomic nervous system and hormones can adjust the rate). The conduction pathway, in order:

1. The **sino-atrial node (SAN)**, a small patch of specialised tissue in the wall of the right atrium, acts as the heart's natural **pacemaker**, spontaneously generating a wave of electrical excitation at regular intervals.
2. This wave spreads rapidly across both atria (cell to cell), causing **atrial systole**.
3. A layer of non-conducting fibrous tissue at the atrioventricular border prevents the wave spreading directly to the ventricles; instead it must pass through the **atrioventricular node (AVN)**, which imposes a brief **delay** (roughly 0.1 s).
4. After the delay, the impulse passes rapidly down the **Bundle of His** — a strand of conducting fibres running down the septum — to the apex (base) of the heart.
5. From the apex, the impulse spreads upward and outward through the ventricle walls via the **Purkyne fibres**, causing **ventricular systole** to begin at the apex and spread upward — squeezing blood efficiently upward and out through the arteries.

The AVN delay is functionally essential: it ensures atrial systole has fully finished (atria completely emptied into the ventricles) *before* ventricular systole begins, so the two do not occur simultaneously (which would be inefficient and could force blood backward). Ventricular contraction beginning at the apex and spreading upward squeezes blood toward the arteries at the top of the ventricles, rather than trapping it at the bottom.

VN **GIẢI THÍCH TIẾNG VIỆT**

Tim có tính **tự động (myogenic)** — tự phát sinh nhịp đập mà không cần xung thần kinh từ bên ngoài. Đường dẫn truyền: **nút xoang nhĩ (SAN)** phát xung → lan khắp hai tâm nhĩ (tâm nhĩ co) → bị trì hoãn ngắn tại **nút nhĩ-thất (AVN)** → truyền nhanh xuống **bó His** đến đỉnh tim → lan lên qua **sợi Purkyne** khiến tâm thất co từ đỉnh lên trên. Độ trễ tại AVN đảm bảo tâm nhĩ co và đẩy hết máu xuống tâm thất **trước khi** tâm thất bắt đầu co.

Ví dụ mẫu · Cardiac output calculation (1)

A person has a resting heart rate of 72 beats/min and a stroke volume of 70 cm^3. Calculate the cardiac output.

Cardiac output $=$ heart rate $\times$ stroke volume $= 72 \times 70 = 5040$ cm^3/min $\approx$ **5.0** dm^3/min — a typical resting value (about 5 litres/min).

Ví dụ mẫu · Cardiac output calculation (2)

During exercise, the same person's heart rate rises to 150 beats/min and stroke volume rises to 100 cm^3. (a) Calculate the new cardiac output. (b) By what factor has cardiac output increased compared with the resting value in the previous example?

(a) $150 \times 100 = 15\,000$ cm^3/min $=$ **15.0** dm^3/min.

(b) $\dfrac{15.0}{5.0} =$ **3.0** — cardiac output has tripled, achieved by simultaneously increasing both heart rate ($\times 2.08$) and stroke volume ($\times 1.43$), since $2.08 \times 1.43 \approx 3.0$.

7.13 Blood Vessels: Structure and Function

Vessel	Wall / lumen	Function
Artery	Thick wall with substantial smooth muscle and elastic tissue; narrow lumen; no valves	Carries blood *away* from the heart at high pressure; elastic tissue stretches and recoils to smooth out the pulsatile pressure from the heart; thick muscular wall withstands and helps maintain this high pressure
Vein	Thin wall (little muscle/elastic tissue); wide lumen; has **valves**	Carries blood *toward* the heart at low pressure; the wide lumen offers low resistance; valves prevent backflow, especially important against gravity in the limbs (assisted by skeletal muscle contraction squeezing the veins)
Capillary	Wall just one cell thick (endothelium only); very narrow, only wide enough for red blood cells to pass in single file	Site of exchange of substances (O2, CO2, glucose, ions, tissue fluid) between blood and tissues; the thin wall minimises diffusion distance

Table 3. Comparison of artery, vein and capillary structure and function.

Ví dụ mẫu · Blood vessel structure–function reasoning

Explain why an artery wall contains a thick layer of elastic tissue in addition to smooth muscle, whereas a vein's wall does not need much of either.

Blood leaves the heart in surges (with each ventricular systole), producing a highly **pulsatile**, high-pressure flow. The elastic tissue in an artery wall stretches during systole (absorbing some of this pressure surge) and recoils during diastole, helping to smooth the flow into a steadier, continuous pressure and preventing the vessel from bursting under repeated pressure surges; the smooth muscle can also constrict/dilate the vessel to help regulate blood flow and pressure. By contrast, blood in veins is already at low pressure and flows in a much steadier, non-pulsatile manner (helped along by contraction of surrounding skeletal muscles and one-way valves), so a vein does not require thick elastic or muscular walls to withstand pressure surges.

Ví dụ mẫu · Comparing pressure and vessel structure

Typical mean blood pressures are approximately 13 kPa in the aorta, 3–4 kPa in a large vein near the heart, and close to 0–1 kPa in the smallest veins of the foot at rest. Explain why the walls of the aorta must be far more resistant to bursting than the walls of a large vein, and why veins in the foot specifically rely heavily on valves and surrounding skeletal muscle.

The aorta carries blood at roughly 10–13 times the pressure found in a large vein, and this pressure surges further with each ventricular systole; its thick, muscular, elastic wall is needed to withstand these repeated high-pressure pulses without rupturing, while the elastic tissue also stretches and recoils to smooth the pulsatile flow. Veins in the foot, especially when standing, carry blood at very low pressure while also working against gravity over a long vertical distance back to the heart; without valves (which prevent backflow between muscle contractions) and the periodic squeezing action of surrounding skeletal muscles (which actively pushes blood along the vein when contracting), blood would tend to pool in the lower limbs rather than returning efficiently to the heart.

7.14 Blood Composition

Blood is composed of: **plasma** (roughly 55% of blood volume — the straw-coloured liquid: water with dissolved plasma proteins such as albumin and fibrinogen, glucose, amino acids, ions, hormones and dissolved CO2, mostly as bicarbonate ions); **erythrocytes** (red blood cells — biconcave discs, no nucleus in mammals, densely packed with haemoglobin, carrying O2 and some CO2); **leucocytes** (white blood cells — including phagocytes such as neutrophils and macrophages, and lymphocytes; central to immune defence, covered in the following unit); and **platelets** (small cell fragments involved in blood clotting).

VN **GIẢI THÍCH TIẾNG VIỆT**

Máu gồm **huyết tương (plasma)** — chứa nước, protein huyết tương, glucose, ion, hormone; **hồng cầu (erythrocyte)** — hình đĩa lõm hai mặt, không nhân, chứa hemoglobin để vận chuyển O2; **bạch cầu (leucocyte)** — tham gia miễn dịch; và **tiểu cầu (platelet)** — tham gia đông máu.

7.15 Haemoglobin and the Oxygen Dissociation Curve

Haemoglobin is a globular protein with a **quaternary structure**: four polypeptide chains (in adult haemoglobin, two α and two β chains), each folded around one **haem group** containing an $Fe^{2}+$ ion, which reversibly binds one molecule of O2. A single haemoglobin molecule can therefore carry up to **four** O2 molecules.

Cooperative binding and the sigmoid curve

Binding of the first O2 molecule causes a small conformational (shape) change in the haemoglobin molecule that **increases its affinity** for subsequent O2 molecules — this is **cooperative binding**. As a result, the graph of % saturation of haemoglobin against partial pressure of oxygen (pO2) is **sigmoid (S-shaped)**: the curve rises slowly at very low pO2 (few molecules bound, harder to bind), rises very steeply over the middle range (each successive O2 binds more easily once earlier ones are bound), then flattens toward saturation at high pO2 (nearly all binding sites occupied).

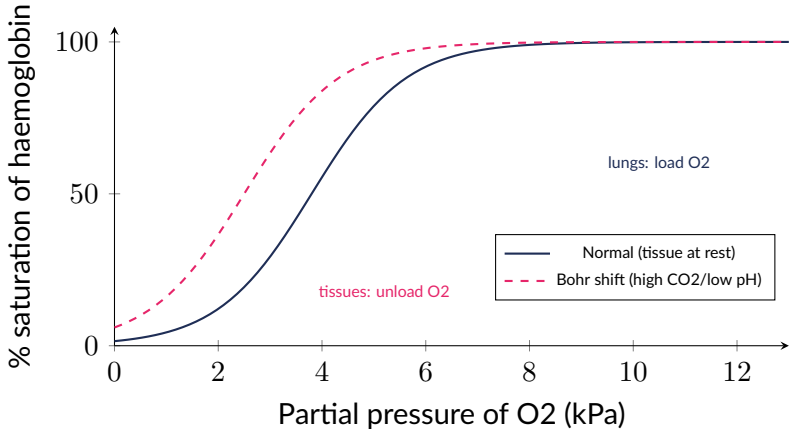


Figure 8. The oxygen dissociation curve. Solid curve: normal conditions. Dashed curve: shifted **right** by the Bohr effect (higher CO2/lower pH at actively respiring tissue), lowering haemoglobin's affinity for O2 at a given pO2 so more oxygen is released exactly where it is needed most.

The Bohr effect

Actively respiring tissue produces CO2, which combines with water (catalysed by carbonic anhydrase) to form carbonic acid, which dissociates into H+ and HCO3−. The rise in H+ concentration (fall in pH) causes a conformational change in haemoglobin that **reduces its affinity for** O2, shifting the dissociation curve to the **right**. At any given pO2, haemoglobin therefore carries a *lower* % saturation than under normal conditions — i.e. it **releases more oxygen** exactly at tissues that are respiring fastest (and so producing the most CO2), efficiently matching oxygen supply to local demand.

VN **GIẢI THÍCH TIẾNG VIỆT**

Hemoglobin có cấu trúc bậc 4 gồm 4 chuỗi polypeptide, mỗi chuỗi mang một nhóm heme chứa $Fe^{2}+$ gắn với 1 phân tử O2 — vậy một phân tử hemoglobin mang tối đa 4 O2. Do liên kết **hợp tác (cooperative)**, đường cong phân ly oxy có dạng **chữ S**. **Hiệu ứng Bohr**: ở mô hô hấp mạnh, nhiều CO2 làm giảm pH, khiến hemoglobin **giảm ái lực với oxy** — đường cong dịch **sang phải** — nghĩa là hemoglobin **nhả oxy dễ hơn** đúng nơi mô cần oxy nhất.

Ví dụ mẫu · Reading percentage saturation from the dissociation curve

Using the normal curve in Figure 8, haemoglobin is approximately 97% saturated at the pO2 found in the lungs ($\approx$ 13 kPa) and approximately 30%–40% saturated at the pO2 typical of actively respiring muscle ($\approx$ 2–3 kPa). Calculate the approximate percentage of the oxygen originally loaded in the lungs that is unloaded by the time blood reaches actively respiring muscle.

Oxygen unloaded $\approx 97\% - 35\% = 62\%$ (using the midpoint of the 30–40% range). So roughly **62% of the oxygen** loaded in the lungs is released to actively respiring muscle — the steep middle portion of the sigmoid curve means a relatively small drop in pO2 (from lungs to tissue) causes a very large drop in % saturation, i.e. efficient unloading.

Ví dụ mẫu · Bohr effect interpretation

At a pO2 of 4 kPa, haemoglobin is about 55% saturated under normal (resting) conditions, but only about 30% saturated in a muscle undergoing intense exercise (high CO2, low pH). Explain the difference and its biological significance.

Intense exercise produces large amounts of CO2, lowering local pH; this is the **Bohr effect**, which reduces haemoglobin's affinity for O2 and shifts the dissociation curve to the right. At the same pO2 (4 kPa), haemoglobin therefore carries less oxygen (30% vs. 55%) — meaning it has released a greater proportion of its oxygen to the muscle. This is highly advantageous: the tissue working hardest (producing the most CO2) automatically receives the greatest additional supply of oxygen exactly when its demand is highest.

7.16 Formation of Tissue Fluid

Tissue fluid formation and return

At the **arterial end** of a capillary bed, blood is still under relatively high **hydrostatic pressure** (generated by the heart), which exceeds the (opposing) pressure due to the water potential of the blood (largely set by dissolved plasma proteins, sometimes called oncotic pressure). The net outward force pushes fluid — water, glucose, ions, amino acids and other small solutes, but

not the large plasma proteins or blood cells — out of the capillary wall into the spaces between cells, forming **tissue fluid**.
As fluid moves along the capillary, hydrostatic pressure falls (progressively less fluid remains inside), while the water potential of the blood remains low (plasma proteins, too large to leave, become relatively more concentrated). By the **venous end** of the capillary, the (now dominant) water-potential difference draws most of the tissue fluid back *into* the capillary by osmosis. The small remaining excess (roughly 10% of the fluid that left) is not reabsorbed directly into the blood; instead it drains into blind-ending **lymphatic vessels** as **lymph**, which is eventually returned to the bloodstream near the subclavian veins.

VN **GIẢI THÍCH TIẾNG VIỆT**

Ở đầu động mạch của mao mạch, **áp suất thuỷ tĩnh** (do tim bơm) cao hơn áp suất thẩm thấu ngược lại (do protein huyết tương tạo ra), nên nước và các chất hoà tan nhỏ bị đẩy ra ngoài tạo thành **dịch mô (tissue fluid)**; protein huyết tương và tế bào máu ở lại trong mao mạch vì quá lớn. Ở đầu tĩnh mạch, áp suất thuỷ tĩnh đã giảm nhiều trong khi áp suất thẩm thấu (do protein) vẫn còn, nên phần lớn dịch mô được hút trở lại mao mạch bằng thẩm thấu. Phần dịch còn dư (khoảng 10%) được hệ **bạch huyết (lymphatic system)** dẫn lưu, đưa trở về máu gần tĩnh mạch dưới đòn.

7.17 Cardiovascular Disease

Atherosclerosis mechanism: damage to the endothelium lining an artery (caused, for example, by high blood pressure or chemicals absorbed from tobacco smoke) triggers a local inflammatory response. Low-density lipoprotein (LDL) cholesterol accumulates within the artery wall; macrophages engulf this lipid, becoming lipid-laden "foam cells" that build up as a fatty streak. Over time this develops into an **atheroma** (plaque) — a build-up of fatty deposits, dead cells, fibrous tissue and sometimes calcium — which narrows the lumen of the artery (**atherosclerosis**), reduces its elasticity, and restricts blood flow. A plaque can rupture, exposing underlying tissue and triggering formation of a blood clot (**thrombosis**); a clot that blocks a coronary artery can cause a myocardial infarction (heart attack), and one that blocks a vessel supplying the brain can cause a stroke.

Key risk factors: a diet high in saturated fat raises blood LDL cholesterol, accelerating plaque formation; chronic high blood pressure damages the artery endothelium, promoting atherosclerosis; smoking introduces chemicals that damage the endothelium and (via nicotine) raises heart rate and blood pressure, while carbon monoxide reduces the oxygen-carrying capacity of the blood; genetic factors (family history, inherited lipid-metabolism conditions) also strongly influence individual risk.

VN **GIẢI THÍCH TIẾNG VIỆT**

Xơ vữa động mạch (atherosclerosis) bắt đầu khi lớp nội mô động mạch bị tổn thương, kích hoạt phản ứng viêm; cholesterol LDL tích tụ trong thành mạch, đại thực bào nuốt lipid tạo "tế bào bọt" (foam cell), hình thành mảng xơ vữa (atheroma) làm hẹp lòng mạch. Mảng xơ vữa có thể vỡ ra, gây hình thành cục máu đông (thrombosis) — nếu chặn động mạch vành sẽ gây nhồi máu cơ tim, nếu chặn mạch não sẽ gây đột quỵ. Các yếu tố nguy cơ chính: chế độ ăn nhiều chất béo bão hoà, huyết áp cao, hút thuốc lá, và yếu tố di truyền.

7.18 Practice Bank --- Part A: Transport in Plants

Bài tập luyện tập

A potometer bubble moves 20 cm along a tube of radius 0.1 cm in 10 minutes. Calculate the rate of water uptake, in cm^3/min.

(A) 0.0628 cm^3/min

(B) 0.628 cm^3/min

(C) 6.28 cm^3/min

(D) 0.00628 cm^3/min

Lời giải chi tiết

$V = \pi(0.1)^2(20) = \pi(0.01)(20) = 0.628$ cm^3. Rate $= 0.628/10 =$ **0.0628** cm^3/min. **(A)**.

Bài tập luyện tập

Radioactively labelled CO2 is fed to a single mature leaf; shortly afterward the label appears in sugars in both the roots and a young developing fruit. What does this best demonstrate about phloem transport?

(A) Phloem always transports sugar downward only

(B) Translocation can move sugar from one source to multiple sinks simultaneously, with direction set by source-sink pressure differences, not a fixed anatomical direction

(C) This proves xylem, not phloem, carried the labelled sugar

(D) Labelled carbon cannot enter the phloem

Lời giải chi tiết

Sugar made from the labelled CO2 (via photosynthesis in the leaf, the source) reached two different sinks (roots and fruit) at once, showing translocation is driven by source-to-sink pressure differences rather than a single fixed anatomical direction. **(B)**.

Bài tập luyện tập

A ringing experiment removes a strip of bark (including phloem, but not xylem) from around a tree trunk. Predict the result and explain why.

(A) The tree wilts immediately, since water transport stops

(B) Tissue above the ring swells with accumulated sugar over time, since translocation to the roots is blocked, while water still rises normally through the intact xylem

(C) Nothing changes, since phloem does not affect transport

(D) The tree stops photosynthesising immediately

Lời giải chi tiết

Removing the phloem (ringing) blocks translocation of sugars downward to the roots, causing sugar (and swelling) to accumulate in the tissue just above the cut, while the deeper, unaffected xylem continues supplying water upward normally — the tree does not wilt immediately, but the roots eventually starve. **(B)**.

Bài tập luyện tập

Which adaptation of a xylem vessel most directly supports the cohesion-tension mechanism of water transport?

(A) Living cytoplasm that actively pumps water upward

(B) A continuous, unbroken, water-filled tube with no cross-walls, allowing an unbroken column of water

(C) Chloroplasts that photosynthesise to generate transport energy

(D) A partially permeable membrane surrounding each vessel

Lời giải chi tiết

Cohesion-tension relies on an unbroken column of water; xylem vessels are dead, hollow, and lack cross-walls between adjacent elements, forming one continuous, low-resistance tube — essential for tension generated at the leaf to be transmitted, unbroken, down to the roots. **(B)**.

Bài tập luyện tập

Explain, in terms of SA:V ratio and diffusion, why a 30-metre-tall tree cannot rely on diffusion alone to supply its leaves with water absorbed by its roots.

Lời giải chi tiết

Diffusion time increases with the square of distance, so over a distance of many metres diffusion would take an impossibly long time. In addition, a large tree has a low SA:V ratio: its volume (and hence total metabolic/water demand) is very large relative to its outer surface area, so simple diffusion across surfaces cannot deliver water fast enough to every cell. A specialised mass transport tissue (xylem), driven by transpiration pull, is required to move water in bulk over such distances.

Bài tập luyện tập

A student claims that pits in xylem vessel walls are a weakness that should be avoided by the plant. Evaluate this claim.

Lời giải chi tiết

The claim is incorrect. Pits are functionally important, not a weakness: they allow lateral movement of water between adjacent vessels, which lets water bypass a blockage (such as an air bubble/embolism) in one vessel by diverting sideways through a pit into a neighbouring, unblocked vessel. Without pits, a single air blockage would completely stop water flow in that vessel for the rest of the plant's life.

Bài tập luyện tập

Water in the apoplast pathway of the root cortex is forced to cross into the symplast at the endodermis. What structure causes this, and what is the key functional consequence for the plant?

(A) The cell wall thickness; it simply slows water down

(B) The Casparian strip (waterproof suberin band); it forces all water/ions through at least one selective membrane, allowing the plant to control which ions enter the xylem

(C) The vacuole; it stores excess water

(D) The nucleus; it directs water flow

Lời giải chi tiết

The Casparian strip, a band of waterproof suberin in the endodermal cell walls, blocks the apoplast pathway completely at this point. This forces water and dissolved ions to cross a selectively permeable plasma membrane (via the symplast) to reach the stele, allowing active, selective control over which mineral ions are permitted to enter the xylem. **(B)**.

Bài tập luyện tập

Two plants of the same species and leaf area are compared: Plant X is kept in still, humid air; Plant Y is kept under a fan in dry air, otherwise identical conditions. Predict and explain which plant shows a faster rate of water uptake in a potometer.

Lời giải chi tiết

Plant Y (fan, dry air) shows the faster rate. Dry air maximises the water-potential/concentration gradient between the saturated leaf air spaces and the atmosphere (compared with humid air, which reduces this gradient). The fan continuously removes the humid boundary layer that would otherwise build up at the leaf surface, maintaining a steep gradient. Both factors independently increase the rate of diffusion of water vapour out of the stomata, and hence the rate of water uptake by the xylem to replace it.

Bài tập luyện tập

During a drought, a plant's guard cells actively pump potassium ions ($K+$) out of the cell in response to the hormone abscisic acid (ABA). Explain the effect this has on stomatal aperture.

Lời giải chi tiết

Pumping $K+$ out of the guard cells raises their solute concentration outside relative to inside, raising the guard cells' water potential. Water therefore leaves the guard cells by osmosis, and they become flaccid. Since the inner (pore-side) wall is thicker and less elastic than the outer wall, a flaccid guard cell straightens rather than bowing, closing the stomatal pore and reducing further water loss during drought stress.

Bài tập luyện tập

Which of the following would you expect to increase the rate of transpiration the most, all else being equal?

(A) Decreasing light intensity from bright to dim

(B) Increasing air humidity from 40% to 90%

(C) Increasing wind speed while keeping temperature and humidity constant

(D) Covering the underside of the leaf (where most stomata are) with an impermeable layer of grease

Lời giải chi tiết

Increasing wind speed removes the humid boundary layer next to the leaf, steepening the concentration gradient for water vapour diffusion and increasing the transpiration rate. The other three options would each *decrease* transpiration (dimmer light closes stomata more; higher humidity reduces the gradient; greasing the lower epidermis blocks most stomata). **(C)**.

Bài tập luyện tập

A potometer bubble moves 15 cm in 3 minutes in bright light, using a capillary tube of internal radius 0.08 cm. Calculate the rate of water uptake in cm^3/min.

Lời giải chi tiết

$V = \pi r^2 h = \pi(0.08)^2(15) = \pi(0.0064)(15) \approx 0.302$ cm^3. Rate $= 0.302/3 \approx$ **0.101** cm^3/min.

Bài tập luyện tập

Explain why a potometer measures the rate of water *uptake* rather than the rate of transpiration directly, and why this is nonetheless considered a good estimate of the transpiration rate.

Lời giải chi tiết

The potometer measures how quickly the cut shoot draws water up the capillary tube (uptake), not water vapour loss from the stomata directly — these are not identical, because a small proportion of the water taken up is retained by the plant (used in photosynthesis, incorporated into growing cells, or used to maintain cell turgor) rather than being lost as vapour. However, since well over 99% of the water taken up by a transpiring shoot is in fact lost through transpiration, uptake is a very close and practically reliable estimate of the transpiration rate.

Bài tập luyện tập

A companion cell actively pumps H+ ions out of its cytoplasm and uses the resulting gradient to co-transport sucrose into an adjacent sieve tube element. What immediate effect does this have on the sieve tube element, and what is the knock-on consequence for water movement?

Lời giải chi tiết

Loading sucrose into the sieve tube element lowers its (solute) water potential. Water then enters the sieve tube element by osmosis from the adjacent xylem, since water moves from a region of higher (less negative) water potential to one of lower (more negative) water potential. This raises the hydrostatic pressure inside the sieve tube at this point (the source), which is the first step in generating the pressure gradient that drives mass flow toward the sink.

Bài tập luyện tập

Which of the following is evidence *against* (or not fully explained by) a purely passive mass-flow mechanism for translocation?

(A) Sap exudes under pressure when a sieve tube is cut

(B) Sucrose concentration is higher in sieve tubes near a source than near a sink

(C) Different solutes in the same sieve tube can sometimes be shown moving at different speeds simultaneously

(D) Ringing experiments cause sugar to accumulate above the cut

Lời giải chi tiết

If mass flow were a single bulk flow of one solution, all dissolved solutes carried within it should move at the same speed. Observations of different solutes moving at different rates within the same sieve tube are therefore not fully explained by the simple mass-flow model. The other three options are consistent with, and support, the mass flow hypothesis. **(C)**.

Bài tập luyện tập

A xylem vessel is compared with a sieve tube element. State **two** structural differences and explain how each relates to their different functions.

Lời giải chi tiết

(1) Xylem vessels are dead at maturity (no cytoplasm/organelles), giving an empty, low-resistance lumen suited to rapid, purely physical (passive) bulk flow of water; sieve tube elements are living (retain a thin cytoplasm layer), which is necessary because active loading/unloading of sucrose (an active, ATP-dependent process, carried out with the help of the adjoining companion cell) is required to establish the pressure gradient that drives phloem transport. (2) Xylem vessel walls are lignified (waterproof, rigid) to withstand the negative pressures (tension) generated during transpiration and to provide mechanical support; sieve tube walls are unlignified (thin cellulose), consistent with the fact that phloem sap moves under positive pressure, not tension, and does not require rigid, waterproofed walls.

Bài tập luyện tập

A plant physiologist measures water potential values along a sieve tube: $\psi = -650$ kPa at the leaf (source) end and $\psi = -120$ kPa at the root (sink) end, with surrounding xylem at a roughly constant $\psi \approx -40$ kPa throughout. At which end of the sieve tube would you expect water to be entering from the xylem fastest, and why?

Lời giải chi tiết

Water enters fastest at the source (leaf) end, where the sieve tube's water potential (-650 kPa) is far more negative than the surrounding xylem's (-40 kPa) — a large water potential difference drives rapid osmotic entry of water into the phloem, raising hydrostatic pressure there. At the sink end, the difference between sieve tube (-120 kPa) and xylem (-40 kPa) is much smaller, so much less water enters (and, as unloading continues, water may in fact leave the sieve tube here instead).

Bài tập luyện tập

Root hair cells greatly increase the surface area available for water and mineral ion uptake. Suggest **one** further reason (besides surface area) why they specifically are elongated rather than simply being ordinary, flatter epidermal cells.

Lời giải chi tiết

The elongated shape allows root hair cells to penetrate further between soil particles and make more extensive, closer contact with the thin films of water surrounding those particles, without the whole root needing to grow further through the soil — maximising contact with the soil water source directly at the point of absorption.

Bài tập luyện tập

A leaf is sprayed with a chemical that specifically blocks the ATP-driven proton pumps in guard cell membranes. Predict the effect on stomatal behaviour in bright light, with reasoning.

(A) Stomata open wider than normal, since more water can enter

(B) Stomata fail to open normally, since $K+$ uptake (which depends on the $H+$ gradient set up by the proton pump) cannot occur, so guard cells cannot become turgid

(C) There is no effect, since guard cell opening does not require active transport

(D) Stomata close permanently and cannot ever reopen even after the chemical is removed

Lời giải chi tiết

Guard cell opening depends on active pumping of $H+$ out of the cell to create an electrochemical gradient that drives $K+$ into the cell through channels. Blocking the proton pumps prevents this $K+$ influx, so guard cells cannot lower their water potential, cannot take up water by osmosis, and cannot become turgid — stomata therefore fail to open properly even in bright light. **(B)**.

Bài tập luyện tập

Explain why the assembly of a potometer must be carried out entirely underwater, and why the shoot must be cut underwater at a slanted angle.

Lời giải chi tiết

If air enters the xylem vessels (an air embolism), it breaks the continuity of the water column, since air bubbles are compressible and cannot transmit tension the way a continuous water column can — this would prevent the cohesion-tension mechanism from working and stop water uptake through that vessel. Assembling the apparatus underwater, and cutting the shoot underwater, prevents any air from entering the cut xylem vessels. Cutting at a slant increases the exposed cut surface area (more vessels available for water uptake) and reduces the chance of the cut surface sealing flat against the tubing, which could block water flow.

Bài tập luyện tập

Which of the following would you expect *not* to change if a whole shoot (leaves and all) is completely enclosed in a sealed, transparent plastic bag while the potometer readings are taken?

(A) The rate of transpiration

(B) The humidity immediately around the leaves

(C) The rate of water uptake measured by the potometer

(D) The plant's need to open stomata for photosynthesis

Lời giải chi tiết

Sealing the shoot in a plastic bag traps water vapour, rapidly raising humidity around the leaves. This reduces the water-potential/concentration gradient driving transpiration, and so decreases both transpiration rate and the potometer's measured uptake rate. It does not remove the plant's underlying need to open stomata for gas exchange/photosynthesis in the light — option (D) — which is the one factor unaffected by the bag. **(D)**.

Bài tập luyện tập

Summarise, in a short paragraph, why the endodermis (with its Casparian strip) is considered the single most important structure controlling what enters the xylem from the root.

Lời giải chi tiết

Without the Casparian strip, water and dissolved mineral ions could travel unimpeded through the apoplast (cell walls) all the way from the soil into the stele and xylem, with no opportunity for the plant to regulate which substances (and in what amounts) enter its transport system. The Casparian strip blocks this route completely at the endodermis, forcing everything through the symplast, i.e. across at least one selectively permeable plasma membrane, where specific membrane transport proteins can selectively admit needed mineral ions (and exclude or limit others) before they reach the xylem — giving the plant active, physiological control over the composition of its xylem sap.

Bài tập luyện tập

A student calculates the rate of water uptake in a potometer as 0.045 cm^3/min using a bubble that moved 18 cm in 4 minutes. Show whether this calculation is consistent with a capillary tube radius of 0.04 cm.

Lời giải chi tiết

$V = \pi r^2 h = \pi(0.04)^2(18) = \pi(0.0016)(18) \approx 0.0905$ cm^3. Rate $= 0.0905/4 \approx 0.0226$ cm^3/min. This does *not* match the student's stated value of 0.045 cm^3/min (which is roughly double the correctly calculated value) — the student's calculation is inconsistent with the given radius; a radius closer to 0.056 cm would be needed to give 0.045 cm^3/min from the same distance/time.

7.19 Practice Bank --- Part B: Transport in Mammals

Bài tập luyện tập

Why does the left ventricle wall need to be much more muscular than the right ventricle wall?

(A) The left ventricle is physically smaller

(B) The left ventricle must generate enough pressure to pump blood around the entire systemic circuit, a far longer/higher-resistance path than the lungs

(C) The left ventricle pumps deoxygenated blood, which is thicker

(D) There is no real difference

Lời giải chi tiết

The right ventricle only pumps a short distance to the nearby lungs; the left ventricle must generate much higher pressure to push blood through the entire systemic circulation. **(B)**.

Bài tập luyện tập

A person's heart rate rises to 150 beats/min during exercise while stroke volume rises to 100 cm^3. Calculate the new cardiac output, in dm^3/min.

(A) 5.0 dm^3/min

(B) 10.5 dm^3/min

(C) 15.0 dm^3/min

(D) 1.5 dm^3/min

Lời giải chi tiết

$150 \times 100 = 15\,000$ cm^3/min $=$ **15.0** dm^3/min. **(C)**.

Bài tập luyện tập

Fetal haemoglobin has a higher affinity for oxygen than adult haemoglobin (its dissociation curve lies to the left of the adult curve). Why is this essential?

(A) It allows the fetus to store excess oxygen for later use

(B) It allows the fetus to load oxygen from the mother's blood at the placenta, where the adult curve/lower affinity would tend to release rather than take up oxygen

(C) It has no functional significance

(D) It prevents the fetus from using oxygen at all

Lời giải chi tiết

At the placenta, fetal blood must extract O2 from maternal blood at relatively low partial pressures. A leftward-shifted (higher-affinity) curve means fetal haemoglobin binds O2 more readily than maternal haemoglobin at the same partial pressure, favouring net transfer of oxygen from mother to fetus. **(B)**.

Bài tập luyện tập

Which vessel type has valves, and why are they necessary there specifically?

(A) Arteries, because pressure is highest there

(B) Veins, because blood pressure is low and valves prevent backflow, especially against gravity

(C) Capillaries, to control exchange

(D) None of the vessels have valves

Lời giải chi tiết

Veins carry blood back to the heart at low pressure; without valves, blood (especially returning from the limbs, against gravity) could flow backward. Valves ensure one-way flow toward the heart. **(B)**.

Bài tập luyện tập

The AV node (AVN) briefly delays the electrical impulse before it spreads to the ventricles. What is the functional significance of this delay?

(A) It has no functional significance

(B) It ensures the atria finish contracting and empty into the ventricles before the ventricles contract

(C) It slows the heart rate permanently

(D) It prevents the ventricles from ever contracting

Lời giải chi tiết

The brief AVN delay allows atrial systole to complete (fully emptying the atria into the ventricles) *before* ventricular systole begins, ensuring efficient, coordinated filling and pumping rather than simultaneous, inefficient contraction. **(B)**.

Bài tập luyện tập

Explain, with reference to pressure changes, why the bicuspid (mitral) valve closes at the very start of ventricular systole.

Lời giải chi tiết

As the left ventricle begins to contract, its internal pressure rises very rapidly and soon exceeds the pressure in the left atrium (which is relatively low and steady). This reversed pressure difference pushes the flaps of the bicuspid valve upward and shut, preventing blood being forced back into the atrium — the valve closes purely because of this pressure difference, not by active muscular closing of the valve itself.

Bài tập luyện tập

A patient's resting stroke volume is 65 cm^3 and resting cardiac output is 4.55 dm^3/min. Calculate their resting heart rate.

Lời giải chi tiết

Cardiac output $=$ heart rate $\times$ stroke volume, so heart rate $=$ $\dfrac{\text{cardiac output}}{\text{stroke volume}} = \dfrac{4550\ \text{cm}^3/\text{min}}{65\ \text{cm}^3} =$ **70** beats/min.

Bài tập luyện tập

Explain why damage to the sino-atrial node (SAN) but not the atrioventricular node (AVN) would most directly disrupt the *initiation* of each heartbeat, rather than the coordination between atria and ventricles.

Lời giải chi tiết

The SAN is the heart's pacemaker: it spontaneously generates the electrical impulse that initiates each heartbeat. If the SAN is damaged, the heart loses its normal, regular trigger for contraction (though a slower, less reliable "backup" pacemaker elsewhere, e.g. the AVN itself, may partially compensate). The AVN's role is different — it delays and then relays an already-generated impulse from the atria to the ventricles via the Bundle of His, coordinating the timing between the two, rather than generating the impulse itself.

Bài tập luyện tập

Which of the following best explains why capillary walls, but not artery or vein walls, are ideally structured for the exchange of substances with tissues?

(A) Capillaries have thick, elastic walls that filter substances

(B) Capillary walls are only one cell thick (endothelium), minimising diffusion distance between blood and tissue fluid

(C) Capillaries have valves that control the direction of exchange

(D) Capillaries carry blood at the highest pressure of all vessels

Lời giải chi tiết

A one-cell-thick wall gives the shortest possible diffusion distance between blood plasma and the surrounding tissue fluid/cells, maximising the rate of exchange of oxygen, carbon dioxide, glucose and other solutes according to Fick's Law. **(B)**.

Bài tập luyện tập

Using the oxygen dissociation curve, explain why haemoglobin is almost fully saturated at the pO2 found in the lungs (≈ 13 kPa) even though the curve is not yet perfectly flat there.

Lời giải chi tiết

At high pO2, nearly all of haemoglobin's oxygen-binding sites are already occupied (cooperative binding has made binding of the remaining sites very favourable), so the curve approaches, but is asymptotic to, 100% saturation. At 13 kPa the curve is in this near-flat, high-saturation region, so haemoglobin loads oxygen very efficiently in the lungs, even though a small margin below 100% remains theoretically possible at a slightly lower pO2.

Bài tập luyện tập

A patient with anaemia has a normal oxygen dissociation curve shape but a reduced total haemoglobin concentration in their blood. Explain why they may still feel breathless even though their haemoglobin's percentage saturation is normal.

Lời giải chi tiết

Percentage saturation describes what fraction of the *available* haemoglobin's binding sites are occupied by oxygen, not the total amount of oxygen carried. With fewer haemoglobin molecules overall (anaemia), even a normal percentage saturation corresponds to a smaller total quantity of oxygen being carried and delivered per unit volume of blood, reducing oxygen delivery to tissues and causing breathlessness, especially during exertion when oxygen

demand rises.

Bài tập luyện tập

Explain, in sequence, the pressure changes and valve movements that occur from the start of ventricular systole to the start of the next ventricular diastole.

Lời giải chi tiết

At the start of ventricular systole, ventricular pressure rises rapidly; as soon as it exceeds atrial pressure, the AV valves are forced shut (producing the "lub" sound). Ventricular pressure continues rising until it exceeds pressure in the aorta/pulmonary artery, at which point the semilunar valves are forced open and blood is ejected. As the ventricles begin to relax (start of diastole), ventricular pressure falls; once it drops below arterial pressure, the resulting brief backflow closes the semilunar valves ("dub" sound). Ventricular pressure continues falling until it drops below atrial pressure, at which point the AV valves reopen, allowing the ventricles to begin refilling.

Bài tập luyện tập

A researcher compares atheroma formation in two groups: one with chronically high blood pressure, one with normal blood pressure, diets and smoking status otherwise matched. Explain why the high blood pressure group is expected to show more extensive atherosclerosis.

Lời giải chi tiết

Chronically high blood pressure subjects the artery endothelium to greater mechanical stress, making it more likely to become damaged. Endothelial damage triggers an inflammatory response and allows LDL cholesterol to accumulate more readily in the artery wall, accelerating the formation of atheromas (fatty plaques) and so more extensive atherosclerosis, compared with a group whose endothelium experiences normal, lower mechanical stress.

Bài tập luyện tập

Which of the following would most directly reduce the oxygen-carrying capacity of the blood, independent of any change in the shape of the oxygen dissociation curve?

(A) A rightward Bohr shift due to increased CO_2

(B) A fall in total haemoglobin concentration (e.g. due to anaemia)

(C) A decrease in body temperature

(D) An increase in blood pH

Lời giải chi tiết

The total amount of oxygen the blood can carry depends directly on the total quantity of haemoglobin present; a fall in haemoglobin concentration reduces the number of oxygen-binding sites available overall, regardless of the shape/position of the dissociation curve (which only describes saturation *per* haemoglobin molecule). **(B)**.

Bài tập luyện tập

Explain why tissue fluid does not normally contain large plasma proteins such as fibrinogen, even though it does contain glucose and ions at similar concentrations to blood plasma.

Lời giải chi tiết

Tissue fluid forms when hydrostatic pressure at the arterial end of a capillary forces fluid out through the capillary wall. Large plasma proteins are too large to pass through the gaps/pores in the capillary wall (and the wall is not permeable to them), so they remain in the blood plasma, while smaller solutes such as glucose, amino acids and ions (dissolved in the water that is forced out) pass through freely and appear in the tissue fluid at similar concentrations to plasma.

Bài tập luyện tập

Explain how the retained large plasma proteins in blood are directly responsible for the reabsorption of most tissue fluid at the venous end of a capillary.

Lời giải chi tiết

Because plasma proteins are too large to leave the capillary, they remain concentrated in the blood, keeping the blood's water potential relatively low throughout the length of the capillary. At the venous end, hydrostatic pressure has fallen substantially (much of the fluid has already left, and pressure has dropped along the vessel), so the water-potential difference (due to the retained proteins) now dominates and draws water back into the capillary from the surrounding tissue fluid by osmosis.

Bài tập luyện tập

A patient's cardiac output at rest is 5.4 dm^3/min with a heart rate of 75 beats/min. During moderate exercise, cardiac output rises to 12.0 dm^3/min while heart rate rises to 120 beats/min. Calculate the stroke volume at rest and during exercise, and comment on the change.

Lời giải chi tiết

Resting: stroke volume $= \dfrac{5400\ \text{cm}^3/\text{min}}{75} = 72\ \text{cm}^3$. Exercise: stroke volume $= \dfrac{12\,000\ \text{cm}^3/\text{min}}{120} = 100\ \text{cm}^3$. Stroke volume increases from 72 to 100 cm^3 (an increase of about 39%), showing that the rise in cardiac output during exercise is achieved through an increase in *both* heart rate and stroke volume, not heart rate alone.

Bài tập luyện tập

Explain why smoking (via carbon monoxide) reduces the effective oxygen-carrying capacity of the blood even though it does not directly change the total haemoglobin concentration.

Lời giải chi tiết

Carbon monoxide (CO) binds to haemoglobin at the same site as oxygen, and does so with a much higher affinity than oxygen, forming stable carboxyhaemoglobin. Haemoglobin molecules bound to CO are effectively unavailable to bind and transport O2. Although the

total number of haemoglobin molecules is unchanged, the proportion of those molecules that are actually able to carry oxygen falls, reducing the effective oxygen-carrying capacity of the blood.

Bài tập luyện tập

Explain why arteries do not have valves, whereas veins do.

(A) Arteries carry blood at high, pulsatile pressure generated directly by the heart, which itself prevents backflow; veins carry blood at low pressure, so valves are needed to prevent it flowing backward, especially against gravity

(B) Arteries are too narrow for valves to fit

(C) Valves would slow blood down too much in arteries

(D) Arteries do not need one-way flow

Lời giải chi tiết

The high pressure generated directly by ventricular systole keeps blood moving forward through arteries without needing valves; by the time blood reaches the veins, pressure has fallen very low (after passing through the high-resistance capillary beds), so valves are needed to prevent backflow, particularly in the limbs where blood must travel against gravity back to the heart. **(A)**.

Bài tập luyện tập

Sketch (in words) how the pressure in the left atrium, left ventricle, and aorta each change over one cardiac cycle, identifying the point at which each valve opens or closes.

Lời giải chi tiết

Left atrium: pressure stays low overall, with a small peak during atrial systole. Left ventricle: pressure starts low (diastole), rises sharply during ventricular systole to a peak well above aortic pressure, then falls sharply during ventricular diastole. Aorta: pressure stays relatively high and fairly steady, rising further as blood is ejected during ventricular systole, then falling slowly during diastole (but staying well above ventricular diastolic pressure due to elastic recoil of the artery walls). The bicuspid valve closes when ventricular pressure first exceeds atrial pressure (start of ventricular systole); the aortic valve opens when ventricular pressure exceeds aortic pressure, and closes again when ventricular pressure falls back below aortic pressure (start of ventricular diastole); the bicuspid valve reopens once ventricular pressure falls back below atrial pressure.

Bài tập luyện tập

Which structural feature allows red blood cells to carry a very large amount of haemoglobin (and hence oxygen) relative to their size?

(A) The presence of a large nucleus

(B) The absence of a nucleus (in mature mammalian erythrocytes), freeing up internal space for haemoglobin

(C) Their large size compared with other blood cells

(D) Numerous mitochondria packed with haemoglobin

Lời giải chi tiết

Mature mammalian red blood cells lack a nucleus (and most other organelles), which frees up internal volume that is instead packed almost entirely with haemoglobin, maximising the cell's oxygen-carrying capacity relative to its size. **(B)**.

Bài tập luyện tập

Explain, using the concept of the Bohr effect, why a runner's actively respiring leg muscles receive more oxygen from the blood than their (much less active) resting arm muscles receive, even though both are supplied by blood with the same haemoglobin % saturation as it leaves the lungs.

Lời giải chi tiết

The actively respiring leg muscles produce far more CO2 than the resting arm muscles, lowering local pH more in the legs. This shifts the local oxygen dissociation curve further to the right in the leg capillaries than in the arm capillaries (Bohr effect), lowering haemoglobin's affinity for oxygen more in the legs. At the same local pO2, haemoglobin in the leg capillaries therefore releases a greater proportion of its oxygen than in the arm capillaries, delivering more oxygen exactly to the tissue with the greatest metabolic demand.

Bài tập luyện tập

A section of coronary artery becomes almost completely blocked by an atheroma that later ruptures, triggering a thrombosis. Explain the likely medical consequence and why it is often sudden and severe.

Lời giải chi tiết

A blood clot (thrombus) forming at the ruptured plaque can completely block blood flow through the coronary artery, cutting off the oxygen supply to the area of heart muscle it supplies. Because cardiac muscle has a very high, continuous demand for oxygen (aerobic respiration to sustain contraction) and very little capacity to survive anaerobically for long, the affected muscle rapidly becomes starved of oxygen and begins to die (myocardial infarction/-heart attack); because the blockage is often sudden (plaque rupture and clot formation can occur rapidly, over minutes), the muscle damage and resulting symptoms can appear abruptly and be severe.

Bài tập luyện tập

Which of the following is *not* a recognised risk factor for cardiovascular disease?

(A) A diet high in saturated fat

(B) Chronic high blood pressure

(C) Smoking tobacco

(D) Regular moderate-intensity aerobic exercise

Lời giải chi tiết

Regular moderate-intensity aerobic exercise is generally associated with cardiovascular benefit, not increased risk; the other three (high saturated fat diet, chronic high blood pressure, smoking) are all recognised risk factors that promote atherosclerosis. **(D)**.

Bài tập luyện tập

Explain why the right side of the heart handles the same total volume of blood per minute as the left side, despite the very different wall thickness of the two ventricles.

Lời giải chi tiết

Because the pulmonary and systemic circuits are connected in series (blood must pass through both, one after the other, to complete one full circuit), the volume of blood pumped by the right ventricle per minute must equal the volume pumped by the left ventricle per minute over time — otherwise blood would build up on one side of the circulation. The difference in wall thickness reflects the difference in *pressure* each ventricle must generate (high for the long systemic circuit on the left, lower for the short pulmonary circuit on the right), not a difference in the volume of blood each pumps.

Bài tập luyện tập

A student states: "Because haemoglobin's dissociation curve is sigmoid, a small drop in pO2 always causes the same drop in % saturation, no matter where on the curve you start." Evaluate this statement.

Lời giải chi tiết

The statement is incorrect. Because the curve is sigmoid (not a straight line), the effect of a given drop in pO2 on % saturation depends on where on the curve you start. Near the flat, high-saturation top of the curve (as in the lungs), a small drop in pO2 causes only a small drop in % saturation. Over the steep middle section of the curve (as in respiring tissue), the same size drop in pO2 causes a much larger drop in % saturation — this steep region is precisely what allows haemoglobin to unload a large proportion of its oxygen over a relatively small range of pO2 at the tissues.

Bài tập luyện tập

Outline the sequence of events, in the correct order, by which an electrical impulse generated at the SAN results in coordinated contraction of all four heart chambers.

Lời giải chi tiết

(1) The SAN spontaneously generates an electrical impulse. (2) The impulse spreads across both atria, causing them to contract together (atrial systole). (3) The impulse reaches the AVN, where it is briefly delayed (allowing the atria to finish emptying into the ventricles). (4) The impulse then passes rapidly down the Bundle of His, a conducting pathway running through the septum, to the apex of the heart. (5) From the apex, the impulse spreads up through the ventricle walls via the Purkyne fibres, causing the ventricles to contract from the apex upward (ventricular systole), efficiently ejecting blood into the arteries.

Bài tập luyện tập

Explain why a build-up of tissue fluid (oedema) can occur if the plasma protein concentration of the blood falls significantly (e.g. due to liver disease or malnutrition).

Lời giải chi tiết

Plasma proteins are the main factor keeping the blood's water potential low, which normally allows most tissue fluid to be reabsorbed by osmosis at the venous end of capillaries. If plasma protein concentration falls, the blood's water potential rises (becomes less negative), reducing the osmotic pull drawing tissue fluid back into the capillaries. More fluid than normal is therefore left behind in the tissues, causing a build-up known as oedema.

Bài tập luyện tập

A person's blood test shows a normal total haemoglobin concentration but an abnormally low blood pH (acidosis) at rest. Predict the likely effect on the position of their oxygen dissociation curve and on oxygen delivery to resting tissues.

Lời giải chi tiết

A low blood pH (high $H+$ concentration) produces a Bohr-type effect even at rest, shifting the oxygen dissociation curve to the right compared with a person of normal pH. This lowers haemoglobin's affinity for oxygen throughout the body, meaning that at the lungs, haemoglobin may load slightly less oxygen than normal (since the curve is shifted right even at high pO2, though this effect is small near saturation), while at the tissues it will unload oxygen somewhat more readily than normal at any given pO2 — increasing the proportion of oxygen delivered to resting tissues relative to a person with normal pH.

CAMBRIDGE INTERNATIONAL AS & A LEVEL • Unit 8

Gas Exchange, Infectious Disease and Immunity

AS Level

Mục tiêu Unit: Cấu tạo phế nang thích nghi với trao đổi khí và cơ chế hô hấp (hít vào/thở ra); tác động của khói thuốc lá (nhựa thuốc, CO, nicotine, hạt bụi mịn) lên hệ hô hấp và tim mạch; bốn nhóm tác nhân gây bệnh (vi khuẩn, virus, nguyên sinh động vật, nấm) và các bệnh truyền nhiễm điển hình; cơ chế hoạt động của kháng sinh và sự tiến hoá kháng kháng sinh; hàng rào bảo vệ không đặc hiệu; đáp ứng miễn dịch đặc hiệu (dịch thể và qua trung gian tế bào); cấu trúc kháng thể; đáp ứng miễn dịch tiên phát/thứ phát; miễn dịch chủ động/thụ động và vaccine; HIV/AIDS; kháng thể đơn dòng.

PART A --- GAS EXCHANGE AND SMOKING

8.1 The Mammalian Gas Exchange Surface

The lungs contain millions of tiny air sacs, **alveoli**, that provide the enormous surface area needed for gas exchange to keep pace with the high metabolic demand of a mammal.

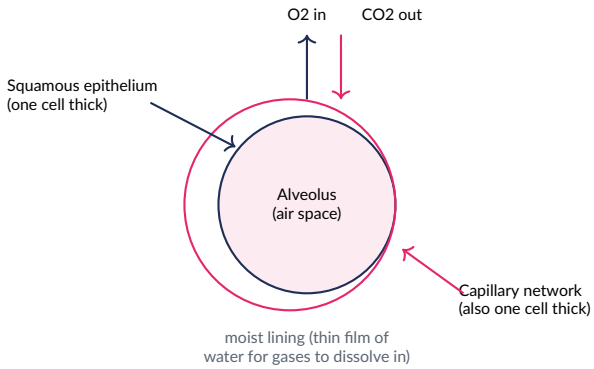


Figure 1. An alveolus and its surrounding capillary network. Both walls are one cell thick (short diffusion pathway); millions of alveoli give the lungs a huge total surface area; a dense capillary network and continuous ventilation/circulation maintain a steep concentration gradient.

Adaptations of the alveolar gas exchange surface

- **Large total surface area**: hundreds of millions of alveoli per lung give a combined surface area of roughly $70\ \text{m}^2$ in an adult human — far greater than could be achieved by a small number of large air sacs of the same total volume.
- **Short diffusion distance**: the alveolar wall (squamous epithelium) and the capillary wall (endothelium) are each only **one cell thick**, and they lie directly against each other, so gases need only cross two thin cell layers (plus their fused basement membranes).

- **Moist lining**: a thin film of moisture lines each alveolus, allowing oxygen to dissolve before diffusing across the epithelium.
- **Rich capillary network**: alveoli are surrounded by a dense network of pulmonary capillaries, maximising the area for gas exchange and ensuring blood flows past in a thin, well-perfused sheet.
- **Ventilation**: continuous breathing movements bring fresh air (high pO2, low pCO2) into the alveoli and remove air with the opposite composition, while continuous blood flow removes oxygenated blood and delivers fresh deoxygenated blood — together maintaining steep concentration gradients for O2 and CO2 across the gas exchange surface at all times.

VN **GIẢI THÍCH TIẾNG VIỆT**

Phế nang (alveolus) thích nghi với trao đổi khí nhờ: **diện tích bề mặt rất lớn** (hàng trăm triệu phế nang); **khoảng cách khuếch tán ngắn** (thành phế nang và thành mao mạch đều chỉ dày 1 tế bào); **lớp lót ẩm** giúp khí hoà tan trước khi khuếch tán; **mạng lưới mao mạch dày đặc** bao quanh; và **sự thông khí liên tục** (hít thở + tuần hoàn máu) duy trì chênh lệch nồng độ khí luôn ở mức cao, giúp khuếch tán diễn ra liên tục và hiệu quả.

8.2 The Mechanics of Breathing

Ventilation moves air in and out of the lungs by creating pressure differences between the lungs and the atmosphere, exploiting the relationship between the volume and pressure of a gas (at constant temperature, pressure and volume of a fixed mass of gas are inversely related — increasing the volume of the thorax lowers the pressure inside it below atmospheric pressure, and vice versa).

Inspiration (breathing in): the external intercostal muscles contract, pulling the rib cage upward and outward; the diaphragm (a dome-shaped sheet of muscle) contracts and flattens, moving downward. Together these increase the volume of the thoracic cavity, which lowers the air pressure inside the lungs below atmospheric pressure — air flows *into* the lungs down this pressure gradient.

Expiration (breathing out), at rest: the external intercostal muscles and diaphragm relax; the rib cage moves down and inward under gravity/elastic recoil, and the diaphragm domes upward again (helped by the elastic recoil of stretched lung tissue), decreasing thoracic volume. This raises the air pressure inside the lungs above atmospheric pressure, so air flows *out*. During forced (deep) expiration, the internal intercostal muscles additionally contract, pulling the ribs down and in more strongly, and abdominal muscles can contract to push the diaphragm up further, increasing the pressure change and forcing more air out faster.

VN **GIẢI THÍCH TIẾNG VIỆT**

Cơ chế hít vào: cơ liên sườn ngoài và cơ hoành co lại, làm tăng thể tích khoang ngực → áp suất trong phổi giảm xuống thấp hơn áp suất khí quyển → không khí đi vào phổi. Cơ chế thở ra (bình thường): các cơ này giãn ra, thể tích khoang ngực giảm → áp suất trong phổi tăng cao hơn áp suất khí quyển → không khí đi ra. Khi thở ra gắng sức, cơ liên sườn trong và cơ bụng co thêm để đẩy khí ra nhanh và mạnh hơn.

Ví dụ mẫu · Interpreting a spirometer-style breathing trace

A resting spirometer trace shows the lung volume oscillating between 2.5 dm^3 and 3.0 dm^3 every 4 seconds, followed by a maximal forced breath in which volume rises from 2.5 dm^3 to

6.0 dm^3 before falling back to 1.2 dm^3 (residual volume not shown as it cannot be exhaled). Calculate: (a) tidal volume, (b) breathing rate (breaths per minute), and (c) vital capacity.

(a) Tidal volume = volume of one normal breath $= 3.0 - 2.5 =$ **0.5** dm^3 (500 cm^3), a typical resting value.

(b) Breathing rate: one full breath cycle takes 4 s, so breaths per minute $= 60/4 =$ **15** breaths/min.

(c) Vital capacity = the maximum volume that can be exhaled after a maximum inhalation $= 6.0 - 1.2 =$ **4.8** dm^3.

8.3 Effects of Tobacco Smoke

Tobacco smoke contains several harmful components that act by different mechanisms.

Component	Mechanism	Consequence
Tar	A mixture of carcinogenic chemicals; also paralyses/destroys the cilia lining the airways and stimulates excess mucus production	Chronic bronchitis (persistent inflammation, excess mucus that cannot be cleared, increased risk of infection); mutations in lung epithelial cell DNA increase risk of lung cancer
Carbon monoxide (CO)	Binds haemoglobin (forming carboxyhaemoglobin) far more strongly than oxygen does, at the same binding site	Reduces the oxygen-carrying capacity of the blood; can increase strain on the heart, which must work harder to deliver the same amount of oxygen
Nicotine	Addictive stimulant; increases heart rate and blood pressure via the nervous system	Increases cardiovascular strain; the addictive property maintains continued exposure to all other harmful smoke components
Particulates	Fine solid particles that accumulate in the alveoli and airways, and directly damage alveolar walls with repeated exposure	Progressive breakdown of alveolar walls reduces total gas exchange surface area (**emphysema**); also contributes to chronic irritation and infection risk

Table 1. Summary of the major harmful components of tobacco smoke and their mechanisms.

Chronic bronchitis, emphysema and lung cancer

Chronic bronchitis: tar destroys the cilia that normally sweep mucus (and trapped particles/-pathogens) up and out of the airways; mucus-producing goblet cells also increase in number and activity. Mucus accumulates in the airways (since it can no longer be cleared), causing persistent inflammation, coughing, and narrowed airways, and providing a favourable environment for bacterial infection.

Emphysema: chemicals and particulates in smoke trigger chronic inflammation that damages and breaks down the elastic tissue and walls of the alveoli. As adjacent alveoli merge into larger, fewer air spaces, the total surface area available for gas exchange is greatly reduced (and elastic recoil, needed to help expel air, is lost), causing breathlessness and reduced oxygen uptake.

Lung cancer: carcinogens in tar cause mutations in the DNA of lung epithelial cells, potentially affecting genes that control the cell cycle (e.g. proto-oncogenes, tumour suppressor genes). Accumulated mutations can lead to uncontrolled cell division, forming a tumour.

VN **GIẢI THÍCH TIẾNG VIỆT**

Khói thuốc lá gây hại qua nhiều cơ chế: **nhựa thuốc (tar)** chứa chất gây ung thư, đồng thời phá huỷ lông mao đường hô hấp khiến chất nhầy tích tụ (viêm phế quản mạn tính); **carbon monoxide (CO)** gắn vào hemoglobin mạnh hơn oxy, làm giảm khả năng vận chuyển oxy của máu; **nicotine** gây nghiện và làm tăng nhịp tim/huyết áp; **hạt bụi mịn** phá huỷ thành phế nang, làm giảm diện tích trao đổi khí (khí phế thũng — emphysema). Đột biến DNA tích luỹ do các chất gây ung thư trong khói thuốc có thể dẫn đến phân chia tế bào không kiểm soát (ung thư phổi).

Ví dụ mẫu · Fick's Law and emphysema

Rate of diffusion $\propto \dfrac{\text{surface area} \times \text{concentration difference}}{\text{diffusion distance}}$. In emphysema, alveolar walls break down, reducing total surface area to half of normal and doubling the average diffusion distance (due to lost elastic recoil and fused, thickened tissue). By what factor does the rate of gas exchange change (assuming concentration difference is unchanged)?

$\dfrac{\text{new rate}}{\text{old rate}} = \dfrac{0.5 \times SA}{2 \times \text{distance}} \Big/ \dfrac{SA}{\text{distance}} = \dfrac{0.5}{2} =$ **0.25** — the rate of gas exchange falls to a quarter of normal, explaining the severe breathlessness seen in emphysema.

(!) Lỗi thường gặp: Đừng nhầm lẫn **viêm phế quản mạn tính (chronic bronchitis)** với **khí phế thũng (emphysema)**: viêm phế quản mạn tính là do **tar** phá huỷ lông mao khiến chất nhầy tích tụ trong đường dẫn khí (đường thở), trong khi khí phế thũng là do **hạt bụi mịn** phá huỷ chính **thành phế nang**, làm giảm diện tích trao đổi khí. Hai bệnh có cơ chế và vị trí tổn thương khác nhau, dù cùng do khói thuốc gây ra.

Ví dụ mẫu · Interpreting lung function data — smoker vs. non-smoker

A non-smoker's forced expiratory volume in one second (FEV_1) is 3.8 dm^3, out of a vital capacity of 4.6 dm^3. A long-term smoker of similar age and height has an FEV_1 of 2.1 dm^3, out of a vital capacity of 4.4 dm^3. (a) Calculate the FEV_1/vital capacity ratio (as a percentage) for each person. (b) Explain what this difference suggests about the smoker's airways.

(a) Non-smoker: $\dfrac{3.8}{4.6} \times 100 \approx$ **83**%. Smoker: $\dfrac{2.1}{4.4} \times 100 \approx$ **48**%.

(b) A markedly lower FEV_1/vital capacity ratio in the smoker (despite a similar overall vital capacity) shows that although the smoker can still eventually exhale a broadly similar total volume of air, they cannot expel it nearly as quickly. This is consistent with narrowed, inflamed, mucus-clogged airways (as in chronic bronchitis) and/or loss of elastic recoil in damaged alveolar tissue (as in emphysema), both of which slow the rate of airflow out of the lungs without necessarily reducing the total volume that can eventually be exhaled.

Ví dụ mẫu · Interpreting carbon monoxide exposure data

A non-smoker's blood typically has less than 2% of haemoglobin bound as carboxyhaemoglobin. A heavy smoker's blood may show 8–10% carboxyhaemoglobin. If a heavy smoker has 9% of their haemoglobin permanently bound to CO (unavailable for oxygen transport) and the same total haemoglobin concentration as a non-smoker, estimate the percentage reduction in the maximum amount of oxygen their blood can carry compared with the non-smoker (assume the non-smoker has negligible carboxyhaemoglobin).

If 9% of haemoglobin is bound to CO, only $100\% - 9\% = 91\%$ remains available to bind oxygen. The maximum oxygen-carrying capacity is therefore reduced by approximately **9**$\%$ compared with a non-smoker with the same total haemoglobin concentration — a persistent handicap present at all times, even before considering any additional short-term effects of smoking (e.g. on heart rate or blood pressure).

PART B --- INFECTIOUS DISEASE

8.4 Pathogens and Infectious Disease

A **pathogen** is any organism (or infectious agent) that causes disease. Four major groups of pathogens are recognised:

Type	Example disease	Transmission	Mechanism / symptoms	Control / prevention
Bacterium	Tuberculosis (TB) — *Mycobacterium tuberculosis*	Airborne droplets (coughing/sneezing)	Bacteria multiply in and damage lung tissue, forming lesions; chronic cough, weight loss, fever	BCG vaccination; antibiotic treatment (multi-drug courses); isolating/treating active cases; improved ventilation and living conditions
Bacterium	Cholera — *Vibrio cholerae*	Contaminated water/food	Toxin causes gut cells to secrete Cl^- (and water) into the lumen, causing severe watery diarrhoea and dehydration	Clean water supply and sanitation; oral rehydration therapy; vaccination in high-risk settings
Virus	HIV/AIDS	Bodily fluids (blood, sexual contact, mother-to-child)	Infects and progressively destroys helper T cells, disabling the immune system (see Part C)	Barrier contraception; needle-exchange/sterile equipment; antiretroviral therapy; screening blood products
Virus	Measles	Airborne droplets	Fever, cough, characteristic rash; can cause serious complications (pneumonia, encephalitis)	MMR vaccination; isolation of cases
Protoctist	Malaria — *Plasmodium*	*Anopheles* mosquito bite (vector)	Parasite multiplies in the liver, then in red blood cells, causing cyclical fever and anaemia	Insecticide-treated bed nets; eliminating mosquito breeding sites; antimalarial drugs; (partial) vaccines
Fungus	Athlete's foot (tinea pedis) — *Trichophyton* spp.	Direct/indirect contact with infected skin or contaminated surfaces (e.g. shared floors)	Fungus digests keratin in the skin, causing itching, cracking and scaling, usually between the toes	Keeping skin dry; not sharing footwear/towels; antifungal creams; good hygiene in shared facilities

Table 2. The four major pathogen types, with a named example disease for each.

VN **GIẢI THÍCH TIẾNG VIỆT**

Bốn nhóm tác nhân gây bệnh chính: **vi khuẩn** (lao — lây qua giọt bắn; tả — lây qua nước bẩn, độc tố gây tiêu chảy nặng), **virus** (HIV/AIDS — lây qua dịch cơ thể, tấn công tế bào T hỗ trợ; sởi — lây qua giọt bắn), **nguyên sinh động vật** (sốt rét do *Plasmodium*, lây qua muỗi *Anopheles* — muỗi là vật trung gian/vector, không phải bản thân mầm bệnh), và **nấm** (nấm da chân — lây qua tiếp xúc trực tiếp/gián tiếp với da nhiễm bệnh hoặc bề mặt dùng chung).

Ví dụ mẫu · Reasoning through a transmission scenario

A village experiences a sudden outbreak of cholera shortly after its main water source becomes contaminated by sewage runoff following flooding. Health workers implement (i) boiling/chlorinating drinking water, and (ii) oral rehydration therapy for affected individuals. Explain how each measure addresses the specific mode of transmission and mechanism of this disease.

Vibrio cholerae is transmitted via contaminated water, so boiling or chlorinating the water supply kills the bacteria before ingestion, directly blocking the transmission route and preventing new infections. Oral rehydration therapy does not treat the underlying bacterial infection itself, but addresses the life-threatening consequence of the toxin's mechanism (a toxin causes gut cells to secrete Cl^- and water into the gut lumen, causing severe watery diarrhoea and dehydration) by replacing the lost water and electrolytes, preventing death from dehydration while the infection runs its course or is treated with antibiotics.

Ví dụ mẫu · Epidemiological transmission reasoning

In a school outbreak of measles, each infected student, on average, goes on to infect 4 other susceptible students before recovering (an effective reproduction number of 4). Starting from a single index case, and assuming no vaccination or immunity in the population, estimate the number of *newly* infected students after 3 further rounds of transmission (i.e. after the index case's contacts, their contacts' contacts, and one further round).

Round 1 (index case's direct contacts): $4^1 = 4$ new cases. Round 2: $4^2 = 16$ new cases. Round 3: $4^3 = 64$ new cases. Total new cases after 3 rounds $= 4 + 16 + 64 =$ **84** students (in addition to the original index case) — illustrating why even a single untreated/unvaccinated case of a highly transmissible disease can rapidly generate a large outbreak, and why vaccination (which removes susceptible individuals from the chain of transmission) is so effective at slowing or preventing this exponential growth.

8.5 Antibiotics and Antibiotic Resistance

How antibiotics work — and why they fail against viruses

Many antibiotics (e.g. **penicillin**) work by disrupting a process essential to bacterial cells but absent (or fundamentally different) in host cells. Penicillin specifically inhibits the enzymes that build peptidoglycan cross-links in the bacterial **cell wall**; without a properly cross-linked wall, growing/dividing bacteria cannot withstand osmotic pressure and burst (lysis). Because human cells have no cell wall at all, penicillin does not damage host cells.

Antibiotics do **not** work against viruses, because viruses are not cells: they have no cell wall, no ribosomes of their own, and no independent metabolism to target — a virus hijacks the host cell's own machinery (ribosomes, enzymes, nucleotides) to replicate. Any drug that disrupted these processes would damage the host's own cells at the same time, since the virus is not carrying out any separate, targetable process of its own.

VN **GIẢI THÍCH TIẾNG VIỆT**

Kháng sinh như **penicillin** ức chế enzyme tổng hợp liên kết ngang peptidoglycan trong **thành tế bào** vi khuẩn, khiến vi khuẩn không chịu được áp suất thẩm thấu và bị vỡ (ly giải) — tế bào người không có thành tế bào nên không bị ảnh hưởng. Kháng sinh **không có tác dụng với virus** vì virus không phải là tế bào: chúng không có thành tế bào, không có ribosome hay bộ máy trao đổi chất riêng — virus "mượn" toàn bộ bộ máy của tế bào chủ để nhân lên, nên không có

quá trình riêng biệt nào của virus để kháng sinh nhắm tới mà không gây hại cho chính tế bào chủ.

Evolution of antibiotic resistance

Within any large bacterial population, random **mutation** occasionally produces a bacterium that happens to carry a gene variant conferring resistance to a particular antibiotic (e.g. an enzyme that breaks down the antibiotic, or an altered target protein the antibiotic can no longer bind). When that antibiotic is used, it acts as a strong **selective pressure**: susceptible bacteria are killed, while the rare resistant individual(s) survive and are far less likely to face competition for resources. The resistant bacteria then reproduce (often very rapidly, given short bacterial generation times), passing the resistance gene(s) to their offspring, and the proportion of resistant bacteria in the population increases over successive generations — natural selection acting on existing genetic variation. Resistance genes can also spread between different bacteria (including different species) via horizontal gene transfer (e.g. plasmid exchange), accelerating the spread of resistance.

Public health measures to reduce the development of antibiotic resistance: only prescribing antibiotics when genuinely necessary (not for viral infections); always completing the full prescribed course (to kill all, not just the most susceptible, bacteria, reducing survivors available to develop/pass on resistance); avoiding routine/unnecessary use of antibiotics in livestock farming; strict infection control in hospitals to limit the spread of resistant strains; ongoing surveillance of resistance patterns; development of new antibiotics/alternative treatments.

VN **GIẢI THÍCH TIẾNG VIỆT**

Kháng kháng sinh tiến hoá theo chọn lọc tự nhiên: đột biến ngẫu nhiên tạo ra một số ít vi khuẩn kháng thuốc trong quần thể; khi dùng kháng sinh, vi khuẩn nhạy cảm bị tiêu diệt còn vi khuẩn kháng thuốc sống sót và sinh sản mạnh, làm tỉ lệ vi khuẩn kháng thuốc trong quần thể tăng dần qua các thế hệ. Biện pháp y tế công cộng để hạn chế: chỉ kê kháng sinh khi thật sự cần thiết, uống đủ liều đủ ngày, hạn chế lạm dụng kháng sinh trong chăn nuôi, kiểm soát nhiễm khuẩn nghiêm ngặt tại bệnh viện.

Ví dụ mẫu · Modelling selection for antibiotic resistance

A bacterial population of $1{,}000{,}000$ cells contains, on average, 1 cell in every 10^6 that carries a pre-existing resistance mutation to a given antibiotic. After treatment kills 99.9% of susceptible bacteria but leaves the resistant cell(s) unaffected, and the surviving population then doubles every 20 minutes for 4 hours, estimate the number of resistant bacteria present at the end of 4 hours (starting from 1 resistant cell), and comment on the significance of incomplete antibiotic courses.

Number of 20-minute doublings in 4 hours $= 240/20 = 12$. Starting from 1 resistant cell: $1 \times 2^{12} =$ **4096** resistant bacteria after 4 hours. If the antibiotic course is stopped early (before all susceptible bacteria are eliminated), a substantial population of susceptible bacteria may also survive and continue reproducing alongside the resistant strain, but crucially, stopping early still allows the resistant strain to multiply essentially unopposed — an incomplete course therefore both risks an incomplete cure and disproportionately favours the survival and spread of resistant bacteria, which is why completing the full prescribed course is emphasised in public health guidance.

PART C --- IMMUNITY

8.6 Non-Specific (Innate) Defences

Non-specific defences act the same way against any pathogen, without recognising a specific antigen:

- **Physical barriers**: intact skin prevents most pathogens from entering the body; mucous membranes (e.g. lining the airways) trap pathogens in mucus, which is then swept away (e.g. by ciliary action) or expelled.
- **Chemical defences**: **lysozyme** (an enzyme present in tears, saliva and mucus) hydrolyses bonds in bacterial cell walls, destroying many bacteria on contact; the acidic pH of the stomach kills many ingested pathogens.
- **Phagocytosis**: phagocytic white blood cells (chiefly **neutrophils** and **macrophages**) engulf and destroy pathogens.

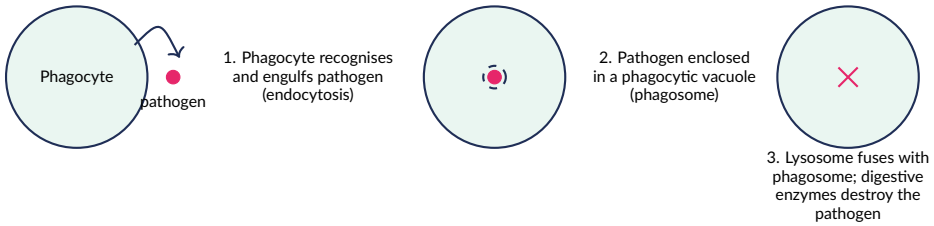


Figure 2. Stages of phagocytosis: (1) the phagocyte recognises and engulfs the pathogen by endocytosis; (2) the pathogen is enclosed within a phagocytic vacuole (phagosome); (3) a lysosome fuses with the phagosome and releases digestive (hydrolytic) enzymes that destroy the pathogen; digested fragments may then be presented on the phagocyte's surface (antigen presentation), linking to the specific immune response.

VN **GIẢI THÍCH TIẾNG VIỆT**

Hàng rào bảo vệ không đặc hiệu (bẩm sinh) phản ứng giống nhau với mọi tác nhân gây bệnh: **da** và **niêm mạc** là rào chắn vật lý; **lysozyme** (trong nước mắt, nước bọt) phá huỷ thành tế bào vi khuẩn; và **thực bào (phagocytosis)** — bạch cầu trung tính (neutrophil) và đại thực bào (macrophage) nuốt và tiêu hoá tác nhân gây bệnh qua ba bước: nuốt (engulf) → tạo không bào thực bào (phagosome) → lysosome dung hợp và tiêu hoá bằng enzyme.

8.7 Specific (Adaptive) Immunity: Humoral Response

An **antigen** is any molecule (usually a protein, often on the surface of a pathogen or on an abnormal/foreign cell) that is recognised by the immune system as foreign and triggers a specific immune response. **Lymphocytes** are the white blood cells responsible for specific immunity: **B lymphocytes** (B cells) mediate the **humoral response** (antibody-based); **T lymphocytes** (T cells) mediate the **cell-mediated response**.

Clonal selection and the humoral response

Each B cell carries a unique receptor (essentially a membrane-bound antibody) able to bind only *one* specific antigen shape. When a B cell's receptor binds its matching antigen (often with additional signals from helper T cells), that B cell is activated and undergoes **clonal selection**: it divides repeatedly by mitosis, producing a large clone of genetically identical cells, all specific to the same antigen. These cells differentiate into two types:

- **Plasma cells**: short-lived cells that manufacture and secrete large quantities of a specific **antibody** into the blood/lymph.
- **Memory cells**: long-lived cells that persist after the infection has been cleared, ready to respond very rapidly if the same antigen is encountered again.

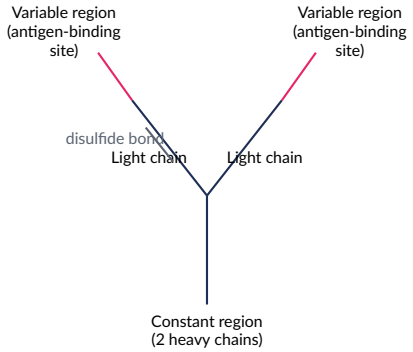


Figure 3. An antibody (immunoglobulin): a Y-shaped protein of **two heavy and two light polypeptide chains**, held together by disulfide bonds. The tips of the two arms form the **variable regions** — identical to each other on a given antibody, and specific (by their tertiary/3-D shape) to one particular antigen — while the base forms the **constant region**, the same across all antibodies of a given class.

How antibodies act against pathogens:

- **Agglutination**: because each antibody has two identical antigen-binding sites, a single antibody can bind two separate pathogens simultaneously, clumping (agglutinating) pathogens together — this immobilises them and makes it far easier for phagocytes to engulf many pathogens at once.
- **Neutralisation**: antibodies bind to and block toxins, or bind to sites on a pathogen's surface needed for it to attach to and infect a host cell, neutralising the threat without necessarily destroying the pathogen directly.
- **Marking for phagocytosis (opsonisation)**: pathogens coated in bound antibody are more readily recognised and engulfed by phagocytes, which have receptors for the constant region of the antibody.

VN **GIẢI THÍCH TIẾNG VIỆT**

Kháng nguyên (antigen) là phân tử lạ kích hoạt đáp ứng miễn dịch đặc hiệu. Tế bào lympho B, khi thụ thể của nó khớp với kháng nguyên tương ứng, trải qua **chọn lọc dòng (clonal selection)**: phân chia tạo dòng tế bào giống hệt nhau, biệt hoá thành **tương bào (plasma cell)** tiết kháng thể và **tế bào nhớ (memory cell)** tồn tại lâu dài. Kháng thể có cấu trúc hình chữ Y gồm 2 chuỗi nặng $+$ 2 chuỗi nhẹ, với vùng biến đổi (variable region) đặc hiệu cho một kháng nguyên nhất định. Kháng thể hoạt động bằng cách: **ngưng kết (agglutination)** tác nhân gây bệnh lại với nhau, **trung hoà (neutralisation)** độc tố/vị trí bám, và **đánh dấu** tác nhân gây bệnh để thực bào dễ nhận diện và nuốt hơn.

Ví dụ mẫu · Antibody structure and agglutination reasoning

Explain why an antibody having *two* identical antigen-binding sites (rather than just one) makes agglutination possible, and why agglutination is beneficial even before any pathogen is actually destroyed.

Because each antibody has two identical binding sites (one on each arm of the Y shape), a single antibody molecule can simultaneously bind an antigen on one pathogen with one arm and an antigen on a second pathogen with the other arm. With many antibodies and many pathogens present, this cross-linking clumps large numbers of pathogens together into aggregates. This is beneficial even before destruction occurs because: (i) clumped, immobilised pathogens can no longer spread through the body or infect new host cells as effectively; and (ii) a single phagocyte can engulf many agglutinated pathogens in one clump far more efficiently than chasing down individual, freely dispersed pathogens one at a time.

8.8 Specific (Adaptive) Immunity: Cell-Mediated Response

T lymphocytes and antigen presentation

Cells that are infected by a pathogen (e.g. a virus) or phagocytes that have engulfed a pathogen typically display fragments of the pathogen's antigens on their own cell surface — **antigen presentation**. **T helper cells** recognise these presented antigens and, once activated, release chemical signals (cytokines) that:

- stimulate B cells to undergo clonal selection and differentiate (activating the humoral response);
- stimulate **T killer (cytotoxic) T cells** to become active;
- stimulate phagocytes to work more effectively.

Activated **T killer cells** bind directly to infected body cells displaying the matching antigen and destroy them (e.g. by inducing programmed cell death), preventing the pathogen (especially viruses, which replicate inside host cells) from continuing to multiply within that cell.

VN **GIẢI THÍCH TIẾNG VIỆT**

Đáp ứng qua trung gian tế bào: tế bào bị nhiễm hoặc thực bào trình diện mảnh kháng nguyên trên bề mặt (**antigen presentation**). **Tế bào T hỗ trợ (T helper)** nhận diện kháng nguyên này và tiết tín hiệu hoá học để kích hoạt cả tế bào B (đáp ứng dịch thể) lẫn **tế bào T độc (T killer/cytotoxic)** — tế bào T độc gắn trực tiếp vào tế bào cơ thể bị nhiễm và tiêu diệt chúng, ngăn mầm bệnh (đặc biệt là virus) tiếp tục nhân lên bên trong.

8.9 Primary and Secondary Immune Responses

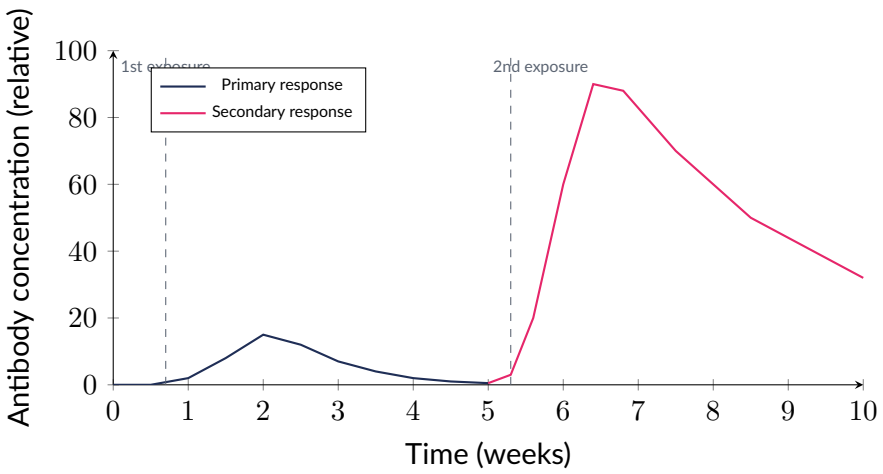


Figure 4. Primary vs. secondary immune response. The primary response (first exposure) is slow to begin and reaches a modest peak. The secondary response (second exposure to the *same* antigen) begins sooner, rises far more steeply, and reaches a much higher peak, because memory B and T cells produced during the primary response are already present and respond immediately.

On first exposure to an antigen, there is a delay (several days) before B cells are identified, undergo clonal selection, and differentiate into plasma cells — the **primary response** is therefore slow and reaches a relatively low peak antibody concentration, and the pathogen may cause noticeable disease symptoms before enough antibody accumulates. Memory B cells (and memory T cells) formed during the primary response persist long-term. On a **second** exposure to the *same* antigen, these memory cells recognise it immediately and rapidly divide/differentiate into plasma cells without the initial delay — the **secondary response** is faster, larger, and often prevents symptomatic disease altogether.

VN **GIẢI THÍCH TIẾNG VIỆT**

Đáp ứng tiên phát (primary response) — lần đầu tiếp xúc kháng nguyên — chậm và đạt đỉnh thấp, vì cần thời gian để chọn lọc dòng tế bào B phù hợp. Đáp ứng thứ phát (secondary response) — lần tiếp xúc thứ hai với **cùng** kháng nguyên — nhanh hơn và đạt đỉnh cao hơn nhiều nhờ đã có sẵn **tế bào nhớ** từ lần đầu, phản ứng ngay lập tức mà không cần "khởi động" từ đầu.

Ví dụ mẫu · Interpreting the primary/secondary response graph

Using Figure 4: (a) estimate the approximate ratio of the secondary peak antibody concentration to the primary peak. (b) Estimate how much sooner the secondary response reaches a substantial antibody level compared with the primary response, and explain the biological reason for the difference.

(a) Primary peak ≈ 15 (relative units); secondary peak ≈ 90. Ratio $\approx 90/15 =$ **6**-fold higher.

(b) The primary response takes roughly 1.5–2 weeks to rise substantially above baseline, whereas the secondary response rises substantially within a few days of re-exposure — several times faster. This is because the primary response must first identify and clonally select a matching B cell essentially "from scratch," while the secondary response begins with a population of memory B cells (produced during the primary response) already present in large numbers and already specific to the antigen, allowing near-immediate differentiation into antibody-secreting plasma cells.

8.10 Active and Passive Immunity; Vaccination and Herd Immunity

Type	Description	Example
Active natural	Antibodies made by the individual's own B cells, triggered by actual infection	Recovering from a natural infection (e.g. chickenpox)
Active artificial	Antibodies made by the individual's own B cells, triggered by deliberate exposure to a harmless form of an antigen	Vaccination
Passive natural	Ready-made antibodies transferred from another individual, without the recipient's B cells being involved	Antibodies crossing the placenta, or in breast milk, from mother to infant
Passive artificial	Ready-made antibodies injected into the individual	Injection of antibodies (e.g. antivenom, or antibody treatment after certain exposures)

Table 3. Active vs. passive immunity, natural vs. artificial.

Active immunity is generally slower to develop (requires the primary response) but long-lasting, since memory cells are produced. **Passive immunity** gives immediate protection (ready-made antibodies act at once) but is short-lived, since the antibodies are gradually broken down/excreted and no memory cells are formed by the recipient — protection fades once the transferred antibodies are gone.

Vaccination introduces a harmless form of a pathogen's antigen (e.g. a weakened/killed pathogen, or an isolated antigen/toxoid) to trigger a primary immune response and memory cell formation, *without* causing the disease itself. A subsequent real infection then triggers a fast, effective secondary response, usually preventing symptomatic disease. When a sufficiently high proportion of a population is vaccinated (**herd immunity**), the pathogen struggles to find enough susceptible hosts to sustain transmission, indirectly protecting even unvaccinated individuals (e.g. those who cannot be vaccinated for medical reasons) by breaking the chain of transmission.

VN **GIẢI THÍCH TIẾNG VIỆT**

Miễn dịch chủ động (do chính cơ thể tạo kháng thể, qua nhiễm bệnh tự nhiên hoặc tiêm vaccine) phát triển chậm hơn nhưng **bền lâu** nhờ tế bào nhớ. **Miễn dịch thụ động** (nhận kháng thể có sẵn từ nguồn khác, qua nhau thai/sữa mẹ hoặc tiêm) có tác dụng **ngay lập tức** nhưng **ngắn hạn** vì không tạo tế bào nhớ. Vaccine đưa vào một dạng kháng nguyên vô hại để kích hoạt đáp ứng tiên phát và tạo tế bào nhớ mà không gây bệnh thật. Khi đủ tỉ lệ dân số được tiêm chủng, **miễn dịch cộng đồng (herd immunity)** hình thành, gián tiếp bảo vệ cả những người chưa/không thể tiêm.

(!) Lỗi thường gặp: Đừng nhầm "**tiêm vaccine**" với "**miễn dịch thụ động**". Vaccine đưa vào kháng nguyên (không phải kháng thể có sẵn), buộc **chính cơ thể** phải tự tạo kháng thể và tế bào nhớ — đây là **miễn dịch chủ động nhân tạo**. Chỉ khi tiêm **kháng thể có sẵn** (đã tạo từ nguồn khác) mới là miễn dịch thụ động.

Ví dụ mẫu · Antibody clearance in passive immunity

Ready-made antibodies injected into a patient (passive immunity) are broken down and cleared from the blood with a biological half-life of approximately 21 days. If a patient is injected with a concentration equivalent to 800 arbitrary units of antibody, estimate the concentration remaining after 63 days, and explain why this decline means passive immunity is inherently short-lived.

63 days $= 3 \times 21$-day half-lives. Remaining concentration $= 800 \times (1/2)^3 = 800/8 =$ **100** arbitrary units after 63 days (and it would continue to halve every further 21 days). Because no memory cells are produced in passive immunity, the patient's own body is not maintaining or replenishing this antibody level in any way — the antibody concentration simply and continuously decays over time until it can no longer provide meaningful protection, in sharp contrast to active immunity, where memory cells allow the body to rapidly regenerate antibody production upon future re-exposure.

Ví dụ mẫu · Distinguishing active and passive immunity

For each scenario, state whether the immunity described is active or passive, and natural or artificial: (i) a baby receives protective antibodies through breast milk; (ii) a person is vaccinated against measles; (iii) a snake-bite patient is injected with ready-made antivenom antibodies; (iv) a person recovers from a natural chickenpox infection and is immune thereafter.

(i) **Passive natural** — antibodies made by another individual (the mother), transferred naturally via milk, no involvement of the baby's own B cells. (ii) **Active artificial** — the person's own B cells are triggered to produce antibodies (and memory cells) by a deliberately administered, harmless antigen. (iii) **Passive artificial** — ready-made antibodies from another source, given by injection. (iv) **Active natural** — the person's own B cells responded to a real infection, producing antibodies and memory cells.

Ví dụ mẫu · Herd immunity threshold reasoning

A pathogen requires roughly 95% of a population to be immune for transmission to be reliably interrupted (herd immunity threshold). In a town of $50{,}000$ people, $42{,}000$ are already immune (through prior infection or vaccination). (a) What percentage of the population is currently immune? (b) How many more people would need to become immune to reach the herd immunity threshold?

(a) $\dfrac{42{,}000}{50{,}000} \times 100 =$ **84**%.

(b) Target number immune $= 0.95 \times 50{,}000 = 47{,}500$. Additional people needed $= 47{,}500 - 42{,}000 =$ **5,500** more people.

8.11 HIV and AIDS

HIV structure and its attack on T helper cells

The Human Immunodeficiency Virus (HIV) is a retrovirus: its genetic material is RNA, which it reverse-transcribes into DNA (using the enzyme reverse transcriptase) once inside a host cell, before this DNA is inserted into the host cell's genome. HIV specifically targets and infects **T helper cells** (recognising a specific surface receptor, CD4, on these cells). Over time, the virus replicates extensively within, and progressively destroys, the T helper cell population.

Because T helper cells are required to activate *both* B cells (for the humoral/antibody response) and cytotoxic T cells (for the cell-mediated response), their progressive loss disables the co-ordination of the entire specific immune response. Once T helper cell numbers fall below a critical level, the immune system can no longer mount effective responses even to pathogens or abnormal cells it would normally control easily — leading to **Acquired Immunodeficiency Syndrome (AIDS)**, characterised by severe, often fatal, **opportunistic infections** (infections by organisms that rarely cause serious disease in people with a functioning immune system) and increased susceptibility to certain cancers.

VN **GIẢI THÍCH TIẾNG VIỆT**

HIV là retrovirus (vật liệu di truyền là RNA, được phiên mã ngược thành DNA nhờ enzyme reverse transcriptase rồi chèn vào bộ gene tế bào chủ), tấn công đặc hiệu **tế bào T hỗ trợ** (thông qua thụ thể CD4). Vì tế bào T hỗ trợ cần thiết để kích hoạt cả tế bào B lẫn tế bào T độc, việc mất dần tế bào T hỗ trợ làm tê liệt toàn bộ đáp ứng miễn dịch đặc hiệu, dẫn đến **AIDS** — hệ miễn dịch suy yếu nghiêm trọng, dễ mắc các **nhiễm trùng cơ hội** (opportunistic infections) mà người khoẻ mạnh bình thường không mắc phải.

Ví dụ mẫu · Interpreting CD4 (T helper cell) count data

A healthy adult typically has a T helper ($CD4^+$) cell count of roughly $800–1{,}200$ cells per mm^3 of blood. AIDS is commonly diagnosed once this count falls below 200 cells per mm^3. A patient's CD4 count falls from 900 to 150 cells per mm^3 over several years of untreated HIV infection. (a) By what factor has the T helper cell count fallen? (b) Explain why a count this low results in a clinical AIDS diagnosis rather than simply "a weaker immune response."

(a) $900/150 = 6$-fold decrease.

(b) Below a certain threshold, there are simply too few T helper cells remaining to adequately activate B cells and cytotoxic T cells across the many different antigens the body encounters. This is a qualitative collapse of immune coordination, not merely a proportionally "weaker" response to any one pathogen — the immune system becomes unable to mount an effective response to numerous opportunistic pathogens simultaneously, which is why this specific threshold marks the transition to a clinical AIDS diagnosis.

8.12 Monoclonal Antibodies

Production principle and applications

Monoclonal antibodies are antibodies that are all identical, derived from a single clone of B cells (or engineered cells based on one), and so are all specific to one single antigen. In outline, they are produced by isolating a single antibody-producing B cell (specific to the target antigen) and fusing it with a rapidly, indefinitely dividing tumour cell to form a **hybridoma**, which combines the B cell's antibody specificity with the tumour cell's ability to divide continuously, allowing large-scale production of one specific antibody.

Applications:

- **Diagnostic tests**, e.g. a home pregnancy test: monoclonal antibodies specific to human chorionic gonadotropin (hCG, present in the urine of pregnant women) are bound to a coloured/enzyme label; if hCG is present, it binds the antibody, producing a visible colour change/line.
- **Targeted cancer therapy**: monoclonal antibodies can be produced that bind specifically to

antigens found on the surface of cancer cells (but not, or far less, on normal cells). These antibodies can mark cancer cells for destruction by the immune system, block signals the cancer cell needs to divide, or be linked to a toxic drug/radioactive label to deliver treatment specifically to the cancer cells while minimising damage to healthy tissue.

VN **GIẢI THÍCH TIẾNG VIỆT**

Kháng thể đơn dòng (monoclonal antibody) là các kháng thể giống hệt nhau, có nguồn gốc từ một dòng tế bào B duy nhất (thường tạo bằng cách dung hợp tế bào B với tế bào khối u thành tế bào lai — hybridoma — để sản xuất với số lượng lớn). Ứng dụng: **xét nghiệm chẩn đoán** (ví dụ que thử thai phát hiện hormone hCG), và **điều trị ung thư đích** (kháng thể gắn đặc hiệu vào kháng nguyên trên bề mặt tế bào ung thư để đánh dấu tiêu diệt, chặn tín hiệu tăng sinh, hoặc mang thuốc/chất phóng xạ đến đúng vị trí khối u, giảm tổn hại mô lành).

Ví dụ mẫu · Monoclonal antibody application reasoning

Explain why a monoclonal antibody-based pregnancy test gives a specific, reliable result for hCG and would not, for example, give a false positive in response to a completely unrelated hormone.

Monoclonal antibodies are all identical copies derived from a single B cell clone, so every antibody molecule in the test has an antigen-binding site of one exact shape, specific (via its variable region's tertiary structure) to the target antigen — in this case, hCG. Because the binding site's shape is complementary only to hCG's specific molecular shape, an unrelated hormone with a different molecular structure will not fit and bind the antibody's binding site, so it will not trigger the colour change/signal — giving high specificity and reliability, in contrast to a mixture of many different (polyclonal) antibodies which might include some that cross-react with unrelated molecules.

8.13 Practice Bank --- Part A: Gas Exchange and Smoking

Bài tập luyện tập

Alveolar surface area is greatly increased by having millions of tiny alveoli rather than two large air sacs. According to Fick's Law, what effect does this have?

(A) It decreases the rate of gas exchange

(B) It increases the rate of gas exchange, since rate is directly proportional to surface area

(C) It has no effect, since only diffusion distance matters

(D) It only affects CO2, not O2

Lời giải chi tiết

By Fick's Law, rate of diffusion is directly proportional to surface area — millions of small alveoli give a vastly greater total surface area than fewer large sacs of the same volume, directly increasing the rate of gas exchange. **(B)**.

Bài tập luyện tập

During inspiration, what combination of muscular changes most directly causes air to flow into the lungs?

(A) External intercostal and diaphragm muscles relax, decreasing thoracic volume

(B) External intercostal muscles and the diaphragm contract, increasing thoracic volume and lowering pressure inside the lungs below atmospheric pressure

(C) Only the diaphragm is involved; the rib cage plays no role

(D) Internal intercostal muscles contract to actively pull air in

Lời giải chi tiết

Contraction of the external intercostal muscles (raising the ribs) and the diaphragm (flattening downward) together increase thoracic volume, which lowers the pressure inside the lungs below atmospheric pressure, causing air to flow in down this pressure gradient. **(B)**.

Bài tập luyện tập

A spirometer trace shows a resting tidal volume of 450 cm^3 and a breathing rate of 16 breaths/min. Calculate the person's pulmonary ventilation rate (volume of air breathed per minute).

Lời giải chi tiết

Pulmonary ventilation rate $=$ tidal volume $\times$ breathing rate $= 450 \times 16 =$ **7,200** cm^3/min $=$ 7.2 dm^3/min.

Bài tập luyện tập

Explain why carbon monoxide is dangerous even at concentrations far too low to be directly toxic to most body cells.

Lời giải chi tiết

Carbon monoxide binds to haemoglobin at the same site as oxygen but with a much higher affinity, forming stable carboxyhaemoglobin that cannot transport oxygen. Even a relatively small proportion of haemoglobin bound to CO therefore meaningfully reduces the blood's total oxygen-carrying capacity, starving tissues (especially the brain and heart, which have very high oxygen demand) of adequate oxygen — the danger arises from impaired oxygen delivery, not from direct cellular toxicity of CO itself at these concentrations.

Bài tập luyện tập

Which component of tobacco smoke is most directly responsible for the addictive nature of smoking?

(A) Tar

(B) Carbon monoxide

(C) Nicotine

(D) Particulates

Lời giải chi tiết

Nicotine is the addictive stimulant in tobacco smoke, acting on the nervous system; this addictive property is what maintains continued exposure to the other harmful components (tar, CO, particulates). **(C)**.

Bài tập luyện tập

Explain, mechanistically, how destruction of cilia in the airways by tar leads to chronic bronchitis.

Lời giải chi tiết

Cilia normally beat continuously to sweep mucus (which traps inhaled particles and pathogens) up and out of the airways. Tar paralyses and eventually destroys these cilia, so mucus (which continues to be produced, often in increased amounts) can no longer be cleared and accumulates in the airways. This causes persistent irritation and inflammation of the airway lining, narrows the airways, and provides a favourable environment for bacterial infection — together producing the persistent cough and inflammation characteristic of chronic bronchitis.

Bài tập luyện tập

A forced spirometer trace shows lung volume rising from 1.5 dm^3 to 5.7 dm^3 during a maximal inhalation, then falling back to 1.5 dm^3 on maximal exhalation. What is this volume called, and what is its value?

(A) Tidal volume; 4.2 dm^3

(B) Vital capacity; 4.2 dm^3

(C) Residual volume; 1.5 dm^3

(D) Total lung capacity; 5.7 dm^3

Lời giải chi tiết

Vital capacity is the maximum volume of air that can be exhaled following a maximum inhalation: $5.7 - 1.5 = \mathbf{4.2}$ dm^3. **(B)**.

Bài tập luyện tập

Explain why emphysema causes breathlessness that worsens progressively over time, using the concept of surface area for gas exchange.

Lời giải chi tiết

Chronic exposure to smoke particulates and associated inflammation progressively breaks down the walls between adjacent alveoli, causing them to merge into fewer, larger air spaces. Although total lung volume may change little, the total surface area available for gas exchange (which depends on having many small alveoli rather than few large ones) falls substantially and continues to fall as more alveolar walls are destroyed, progressively reducing the rate of oxygen uptake (and carbon dioxide removal) and causing increasingly severe breathlessness.

Bài tập luyện tập

Which of the following is *not* a structural adaptation of the alveolar gas exchange surface?

(A) One-cell-thick epithelial wall

(B) A dense capillary network

(C) A thick layer of muscle surrounding each alveolus

(D) A moist internal lining

Lời giải chi tiết

Alveolar walls are thin (one cell thick) precisely to minimise diffusion distance; a thick muscular layer would greatly increase diffusion distance and is not a feature of alveoli (unlike, for example, arteries). **(C)**.

Bài tập luyện tập

A smoker's carboxyhaemoglobin level is measured at 7%. Assuming the same total haemoglobin concentration as a non-smoker with negligible carboxyhaemoglobin, estimate the percentage reduction in maximum oxygen-carrying capacity.

Lời giải chi tiết

If 7% of haemoglobin is permanently bound to CO, only 93% remains available to bind oxygen, so the maximum oxygen-carrying capacity is reduced by approximately **7**$\%$ compared with the non-smoker.

Bài tập luyện tập

Explain why forced (not resting) expiration requires contraction of the internal intercostal muscles as well as the abdominal muscles.

Lời giải chi tiết

At rest, expiration occurs passively as the external intercostal muscles and diaphragm relax and elastic recoil of the lungs and rib cage reduces thoracic volume. During forced expiration, a greater and faster reduction in thoracic volume (and hence a larger pressure increase) is needed to expel air quickly: contraction of the internal intercostal muscles actively pulls the ribs down and inward more forcefully, while contraction of the abdominal muscles pushes the abdominal contents (and hence the diaphragm) upward further than passive relaxation alone would achieve, together producing a greater reduction in thoracic volume and a faster, more forceful expiration.

Bài tập luyện tập

A patient's vital capacity is unchanged after developing emphysema, but their FEV_1/vital capacity ratio has fallen substantially. Explain why total volume exhaled can remain similar while the *rate* of exhalation falls.

Lời giải chi tiết

Vital capacity depends mainly on the total elastic stretch of the lungs/chest and the strength of the respiratory muscles, which may be relatively unaffected in early emphysema. FEV_1 (volume exhaled in the first second) depends much more on how quickly air can flow out, which is reduced when alveolar walls break down (losing elastic recoil that normally helps push air out quickly) and/or airways become narrowed/obstructed — so the same total volume can eventually be exhaled, but far more slowly, lowering the FEV_1/vital capacity ratio.

Bài tập luyện tập

Explain why increasing wind speed across a spirometer-independent measure (transpiration) is not relevant to gas exchange in the lungs, but ventilation rate is the analogous mammalian factor that maintains a steep diffusion gradient at the alveolar surface.

Lời giải chi tiết

In plants, wind removes the humid air layer around leaves, maintaining a steep water-potential gradient for transpiration. In mammals, the equivalent principle is maintaining steep O2/CO2 concentration gradients across the alveolar wall: continuous ventilation (breathing) constantly replaces alveolar air with fresh atmospheric air (high pO2, low pCO2), while continuous blood flow through pulmonary capillaries constantly removes oxygenated blood and delivers fresh deoxygenated blood — together maintaining the steep gradients needed for rapid diffusion, analogous to wind's role in transpiration.

Bài tập luyện tập

Which of the following would most directly increase the rate of gas exchange at the alveolar surface, according to Fick's Law?

(A) Thickening the alveolar epithelium

(B) Reducing the density of the surrounding capillary network

(C) Increasing ventilation rate to maintain a steeper concentration gradient across the gas exchange surface

(D) Reducing total alveolar surface area

Lời giải chi tiết

By Fick's Law, rate of diffusion is proportional to the concentration difference (as well as surface area, and inversely proportional to diffusion distance). Increasing ventilation rate replenishes fresh air faster, maintaining a steeper concentration gradient for O2 and CO2 across the gas exchange surface, directly increasing the rate of gas exchange. The other three options would each decrease the rate of gas exchange. **(C)**.

8.14 Practice Bank --- Part B: Infectious Disease

Bài tập luyện tập

Which statement correctly distinguishes a pathogen from a vector?

(A) A pathogen and a vector are the same thing

(B) A pathogen is the disease-causing organism itself; a vector is an organism (often unaffected by the disease) that transmits the pathogen between hosts

(C) A vector always causes disease directly

(D) A pathogen only refers to bacteria

Lời giải chi tiết

A pathogen is the actual disease-causing organism/agent (e.g. *Plasmodium*, the malaria parasite); a vector is a separate organism that transmits the pathogen from one host to another without necessarily being harmed by it itself (e.g. the *Anopheles* mosquito, which transmits *Plasmodium* but does not itself suffer from malaria). **(B)**.

Bài tập luyện tập

Explain why controlling mosquito populations (e.g. eliminating standing water breeding sites, insecticide-treated bed nets) is an effective public health strategy against malaria, even though it does not directly target *Plasmodium* itself.

Lời giải chi tiết

Malaria is transmitted specifically via bites from *Anopheles* mosquitoes acting as a vector; *Plasmodium* cannot spread from person to person without this vector. By reducing mosquito numbers and preventing mosquito bites (bed nets), the transmission route itself is disrupted, breaking the cycle of infection between human hosts even without any drug or vaccine acting directly on the parasite.

Bài tập luyện tập

Which of the following diseases is caused by a fungus?

(A) Tuberculosis
(B) Cholera
(C) Athlete's foot
(D) Malaria

Lời giải chi tiết

Athlete's foot (tinea pedis) is caused by a fungus (e.g. *Trichophyton* species) that digests keratin in skin; tuberculosis and cholera are bacterial, and malaria is caused by a protoctist parasite. **(C)**.

Bài tập luyện tập

Penicillin inhibits the enzymes responsible for cross-linking peptidoglycan in bacterial cell walls. Explain why this makes penicillin effective against bacteria but harmless to human cells.

Lời giải chi tiết

Bacterial cells rely on a rigid, cross-linked peptidoglycan cell wall to withstand internal osmotic pressure; without proper cross-linking (blocked by penicillin), the wall cannot resist this pressure and the bacterial cell bursts (lysis), especially during growth/division when new wall material is being made. Human cells have no cell wall at all, so this specific target simply does not exist in human cells — penicillin has nothing to disrupt in them, explaining its selective toxicity to bacteria.

Bài tập luyện tập

Explain why a doctor would not prescribe an antibiotic for a patient with a common cold (caused by a virus).

Lời giải chi tiết

Antibiotics work by disrupting processes specific to bacterial cells (e.g. cell wall synthesis) or bacterial metabolism. Viruses are not cells: they have no cell wall, no independent metabolism, and no ribosomes of their own, relying entirely on the host cell's own machinery to replicate. There is therefore no bacterial-specific target for an antibiotic to act on in a viral infection, so

antibiotics would have no effect on the virus (while potentially still causing side effects and contributing unnecessarily to antibiotic resistance in the patient's normal bacterial flora).

Bài tập luyện tập

A population of bacteria is exposed to an antibiotic. A small number of bacteria, which happened to already carry a resistance mutation before exposure, survive and reproduce, while susceptible bacteria are killed. Which statement best describes this process?

(A) The antibiotic caused the resistance mutation to appear

(B) Natural selection acted on pre-existing genetic variation: resistant bacteria that already existed survived and reproduced, increasing their proportion in the population

(C) Antibiotic resistance cannot evolve, only be inherited from birth

(D) All bacteria in the population became resistant simultaneously

Lời giải chi tiết

The resistance mutation existed in the population *before* antibiotic exposure (a random mutation, unrelated to the presence of the antibiotic); the antibiotic then acted as a selective pressure that killed susceptible bacteria while leaving already-resistant individuals to survive and reproduce, increasing the resistant proportion of the population over generations — classic natural selection acting on pre-existing variation, not the antibiotic "causing" or "creating" the resistance itself. **(B)**.

Bài tập luyện tập

Explain why failing to complete a full prescribed course of antibiotics increases the risk of resistant bacteria surviving and spreading.

Lời giải chi tiết

A full course is designed to kill essentially all of the target bacteria, including those that are less susceptible (but not fully resistant). Stopping early leaves a larger surviving population, which is likely to include a higher proportion of less-susceptible or partially resistant bacteria (since the most susceptible individuals are killed fastest, early in the course). These survivors can then continue to reproduce, potentially spreading and passing on resistance genes, and may cause a relapse of infection that is now harder to treat with the same antibiotic.

Bài tập luyện tập

A bacterial culture of 2×10^5 cells contains 2 cells with a pre-existing resistance mutation to an antibiotic. After treatment eliminates 99.99% of susceptible bacteria and the surviving resistant cells double every 30 minutes, how many resistant bacteria are present after 3 hours?

Lời giải chi tiết

Number of 30-minute doublings in 3 hours $= 180/30 = 6$. Starting from 2 resistant cells: $2 \times 2^6 = 2 \times 64 =$ **128** resistant bacteria after 3 hours.

Bài tập luyện tập

Explain why horizontal gene transfer (e.g. plasmid exchange) between bacteria is a particular concern for the spread of antibiotic resistance, compared with resistance spreading only via normal reproduction.

Lời giải chi tiết

Normal reproduction only passes resistance genes vertically, from a resistant bacterium to its own direct offspring, restricting spread to one lineage. Horizontal gene transfer allows a resistance gene (often carried on a plasmid) to be transferred directly between unrelated bacteria, including different species, without either party needing to reproduce first. This can spread resistance far more rapidly and broadly across a bacterial population (and even between different pathogens) than reproduction alone would allow.

Bài tập luyện tập

Cholera is transmitted via contaminated water, while tuberculosis is transmitted via airborne droplets. Explain why improving sanitation/water treatment would be expected to reduce cholera cases far more than it would reduce tuberculosis cases.

Lời giải chi tiết

Public health measures are most effective when they directly target the actual transmission route of a disease. Cholera transmission depends specifically on ingestion of the bacterium via contaminated water/food, so improving water treatment and sanitation directly blocks its main transmission route. Tuberculosis, however, is transmitted through airborne respiratory droplets and does not depend on contaminated water at all, so improving water sanitation would have little to no direct effect on tuberculosis transmission, which instead requires measures targeting airborne spread (e.g. isolation, ventilation, vaccination).

Bài tập luyện tập

Which of the following statements about *Plasmodium* (the malaria parasite) is correct?

(A) It is a bacterium that is destroyed by antibiotics

(B) It is a protoctist that reproduces first in the liver, then within red blood cells

(C) It is a virus that infects white blood cells

(D) It is transmitted directly from person to person without any vector

Lời giải chi tiết

Plasmodium is a protoctist (eukaryotic parasite); after being introduced by an infected *Anopheles* mosquito, it first multiplies within liver cells before infecting and reproducing within red blood cells, causing the cyclical fever characteristic of malaria. **(B)**.

Bài tập luyện tập

A new antiviral drug is proposed that works by inhibiting reverse transcriptase, an enzyme HIV uses to convert its RNA genome into DNA. Explain why this drug is expected to be far less effective against a bacterial infection such as tuberculosis.

Lời giải chi tiết

Reverse transcriptase is an enzyme specific to retroviruses such as HIV, used to convert their RNA genome into DNA before insertion into the host genome. Bacteria such as *Mycobacterium tuberculosis* have their own DNA genome and do not use reverse transcriptase at any stage of their life cycle, so a drug targeting this specific viral enzyme has no equivalent target in bacterial cells and would be expected to have little or no effect on a bacterial infection like tuberculosis.

Bài tập luyện tập

Which measure would be most effective at directly reducing person-to-person transmission of an airborne bacterial disease such as tuberculosis in a crowded setting?

(A) Boiling drinking water

(B) Improved ventilation and isolating/treating active, infectious cases

(C) Eliminating standing water

(D) Wearing gloves when handling food

Lời giải chi tiết

Tuberculosis spreads via airborne droplets, so measures that reduce airborne transmission — improving ventilation (diluting/removing infectious droplets from shared air) and isolating and treating people with active, infectious disease (reducing the source of new droplets) — most directly target its actual transmission route. The other options target water-borne or food-borne/vector-borne transmission routes, which are not relevant to tuberculosis. **(B)**.

8.15 Practice Bank --- Part C: Immunity

Bài tập luyện tập

A patient receives an injection of ready-made antibodies against a snake venom toxin, giving immediate but short-lived protection. What type of immunity is this?

(A) Active natural immunity

(B) Active artificial immunity

(C) Passive artificial immunity

(D) Passive natural immunity

Lời giải chi tiết

The antibodies were made by another source (not the patient's own B cells) and given *artificially* by injection — this is **passive artificial immunity**. It is immediate but temporary because no memory cells are produced by the patient. **(C)**.

Bài tập luyện tập

Following vaccination, a graph of antibody concentration over time shows a small, slow rise after the first dose but a much faster, larger rise after a booster dose weeks later. What explains the difference?

(A) The booster dose contains a different, stronger antigen

(B) Memory cells produced after the first exposure allow a faster, larger secondary response on re-exposure to the same antigen

(C) The first dose had no effect at all

(D) Antibody production always weakens with a second exposure

Lời giải chi tiết

The first dose triggers a primary response, producing memory B and T cells specific to that antigen. On the booster (second) exposure, these memory cells respond immediately, dividing rapidly into plasma cells — producing antibodies faster and in far greater quantity than the primary response. **(B)**.

Bài tập luyện tập

HIV specifically infects and destroys helper T cells. Why does this cripple the immune system so severely?

(A) Helper T cells directly digest all pathogens by phagocytosis

(B) Helper T cells are needed to activate both B cells (antibody production) and cytotoxic T cells, so their loss disables both major arms of specific immunity

(C) Helper T cells are only involved in skin barrier defence

(D) Losing helper T cells has no effect on B cells

Lời giải chi tiết

Helper T cells release signalling chemicals that activate B lymphocytes (to make antibodies) and cytotoxic T cells (to kill infected cells) — losing helper T cells therefore disables the coordination of the whole specific immune response, leaving the body vulnerable to opportunistic infections (AIDS). **(B)**.

Bài tập luyện tập

Explain, in the correct order, the three main stages of phagocytosis.

Lời giải chi tiết

(1) The phagocyte recognises the pathogen (often via antibody coating/opsonisation) and engulfs it by endocytosis, enclosing it within a membrane-bound vesicle. (2) This forms a phagocytic vacuole (phagosome) inside the phagocyte. (3) A lysosome fuses with the phagosome and releases hydrolytic (digestive) enzymes that break down and destroy the pathogen; fragments of the pathogen's antigens may then be displayed on the phagocyte's surface (antigen presentation), linking innate to specific immunity.

Bài tập luyện tập

Explain why lysozyme is classified as a non-specific (innate) defence rather than part of the specific immune response.

Lời giải chi tiết

Lysozyme acts the same way against any bacterium that has a peptidoglycan cell wall, hydrolysing bonds in that wall regardless of the particular species or strain — it does not recognise or respond differently to a specific antigen shape. This lack of antigen-specific recognition (unlike antibodies or T-cell receptors, which bind one particular antigen shape) is what makes lysozyme a non-specific, innate defence.

Bài tập luyện tập

Which structural feature of an antibody's variable region explains why a given antibody can bind only one specific antigen (or a small number of very similar ones)?

(A) Its constant amino acid sequence, identical in every antibody

(B) Its unique tertiary (3-D) shape, formed by a specific amino acid sequence, complementary to one particular antigen shape

(C) The presence of disulfide bonds, found in all antibodies equally

(D) Its large overall molecular size

Lời giải chi tiết

The variable region's specific amino acid sequence folds into a unique tertiary structure/shape, complementary (like a lock and key) to one particular antigen's shape; this structural complementarity, unique to each antibody clone, is what gives antibody-antigen binding its specificity. **(B)**.

Bài tập luyện tập

A person vaccinated against measles as a child is exposed to the measles virus 20 years later and shows no symptoms of disease. Explain this outcome in terms of memory cells.

Lời giải chi tiết

The original vaccination triggered a primary immune response against the measles antigen, producing long-lived memory B cells (and memory T cells) specific to it, which persisted for the subsequent 20 years. On re-exposure to the real virus, these memory cells recognise the antigen immediately and mount a rapid, large secondary response — producing sufficient antibody so quickly that the virus is cleared before it can replicate enough to cause noticeable symptoms.

Bài tập luyện tập

Explain why passive immunity (e.g. antibodies received via the placenta) does not provide long-term protection, even though it can be life-saving in the short term.

Lời giải chi tiết

Passive immunity involves antibodies made by another individual, transferred ready-made to the recipient; the recipient's own B cells are never triggered to divide or differentiate, so no memory cells are produced. The transferred antibodies themselves are gradually broken down and cleared from the body over weeks to months, and once they are gone, no lasting immunological memory remains to protect against future exposure to the same antigen — hence protection is only temporary.

Bài tập luyện tập

A monoclonal antibody is developed that binds specifically to a protein found only on the surface of a particular type of cancer cell. Suggest **two** distinct ways this antibody could be used therapeutically.

Lời giải chi tiết

(1) The antibody could be administered alone to bind the cancer-specific surface protein, marking the cancer cells for destruction by the patient's own immune system (e.g. triggering phagocytosis or recruitment of cytotoxic immune cells), while largely sparing normal cells that lack this surface protein. (2) The antibody could be chemically linked to a cytotoxic drug or radioactive label, so that binding to the cancer cell specifically delivers the toxic payload directly to the tumour, minimising damage to healthy tissue compared with a drug delivered non-specifically throughout the body.

Bài tập luyện tập

Which of the following best explains why herd immunity can protect individuals who cannot be vaccinated (e.g. due to a medical condition)?

(A) Unvaccinated individuals develop immunity automatically over time

(B) With enough of the surrounding population immune, the pathogen has too few susceptible hosts to sustain a chain of transmission, reducing the unvaccinated individual's chance of ever being exposed

(C) Vaccinated individuals cannot carry or transmit the pathogen under any circumstances

(D) Herd immunity has no effect on transmission, only on individual symptoms

Lời giải chi tiết

When a sufficiently high proportion of the population is immune, the pathogen cannot easily find enough new susceptible hosts to maintain its spread through the population — this breaks the chain of transmission and reduces the probability that any given unvaccinated individual will encounter an infectious case, indirectly protecting them even without vaccination themselves. **(B)**.

Bài tập luyện tập

Explain why cytotoxic (T killer) T cells, rather than antibodies, are particularly important for eliminating cells that are already infected by a virus.

Lời giải chi tiết

Once a virus has entered a host cell, it replicates using the host cell's own internal machinery, largely hidden from antibodies circulating in the blood/lymph, which can only bind antigens accessible outside cells (e.g. free virus particles, or antigens displayed on a cell surface). Cytotoxic T cells recognise infected cells specifically because those cells display fragments of viral antigen on their surface (antigen presentation); the cytotoxic T cell can then bind directly to and destroy the infected cell itself, preventing it from producing and releasing further virus particles — a task antibodies alone cannot achieve once the virus is established inside a cell.

Bài tập luyện tập

A patient's serum antibody levels are measured after a first vaccine dose and again after a booster dose 8 weeks later. Antibody concentration after the first dose peaked at 20 arbitrary units after 14 days; after the booster, it peaked at 150 arbitrary units after only 4 days. Calculate (a) the fold-increase in peak antibody concentration, and (b) the reduction in days to reach peak concentration, and explain the underlying cause.

Lời giải chi tiết

(a) $150/20 = \mathbf{7.5}$-fold increase in peak concentration. **(b)** Time to peak fell from 14 days to 4 days, a reduction of **10** days. Both changes reflect the secondary immune response: memory B cells generated by the first dose are already present in large numbers after the booster and recognise the antigen immediately, allowing much faster clonal expansion into antibody-secreting plasma cells, producing a faster, larger rise in antibody concentration than the primary response required.

Bài tập luyện tập

Explain why a person who has recovered from HIV-related opportunistic infections is still considered to have a compromised immune system, even during periods when they show no active infection symptoms.

Lời giải chi tiết

HIV continues to infect and destroy T helper cells throughout the course of infection (unless controlled by antiretroviral therapy), progressively reducing the T helper cell population even between episodes of symptomatic opportunistic infection. Because T helper cells are required to coordinate both humoral and cell-mediated responses to *any* new pathogen encountered, a low T helper cell count leaves the person persistently vulnerable to future infections, regardless of whether they currently show symptoms — the underlying immune deficiency (low T helper cell numbers) does not resolve on its own between infections.

Bài tập luyện tập

Distinguish between an antigen and an antibody, using one sentence for each.

Lời giải chi tiết

An **antigen** is a molecule (typically a protein), often found on the surface of a pathogen or abnormal cell, that is recognised as foreign and triggers a specific immune response. An **antibody** is a Y-shaped protein produced by plasma cells (derived from B lymphocytes) that binds specifically to one particular antigen via its variable regions, helping to neutralise, agglutinate, or mark that antigen's source for destruction.

Bài tập luyện tập

Explain why widespread use of a highly effective vaccine can lead to a disease becoming rare even among people who were never vaccinated themselves.

Lời giải chi tiết

As vaccination coverage rises, the proportion of the population susceptible to the disease falls. Once coverage exceeds the herd immunity threshold, the pathogen can no longer reliably find enough new susceptible hosts to sustain ongoing transmission within the population, so the number of circulating cases falls dramatically. Because chains of transmission are broken throughout the population, even unvaccinated individuals face a much-reduced chance of ever encountering an infected person, so the disease becomes rare among them too, despite their own lack of direct immunity.

Bài tập luyện tập

A B cell specific to a particular bacterial antigen is activated and undergoes clonal selection. State **two** distinct cell types it differentiates into, and the specific role of each.

Lời giải chi tiết

(1) **Plasma cells**: short-lived cells that synthesise and secrete large quantities of antibody specific to the activating antigen, providing the immediate antibody supply needed to help clear the current infection. (2) **Memory cells**: long-lived cells that do not secrete large amounts of antibody immediately, but persist in the body and allow a much faster, larger secondary response if the same antigen is encountered again in future.

Bài tập luyện tập

A researcher proposes a new vaccine that uses an inactivated (killed) form of a virus rather than a live attenuated form. Explain **one** advantage and **one** disadvantage of using a killed, rather than a live attenuated, vaccine.

Lời giải chi tiết

Advantage: a killed (inactivated) virus cannot replicate at all in the recipient, so there is no risk of it reverting to a disease-causing form or causing infection in individuals with a weakened immune system, making it generally safer for vulnerable populations. **Disadvantage:** because the antigen does not replicate or persist in the body, it may trigger a weaker or shorter-lived immune response (fewer memory cells, lower antibody titres) than a live attenuated vaccine, often requiring multiple booster doses to achieve and maintain adequate long-term protection.

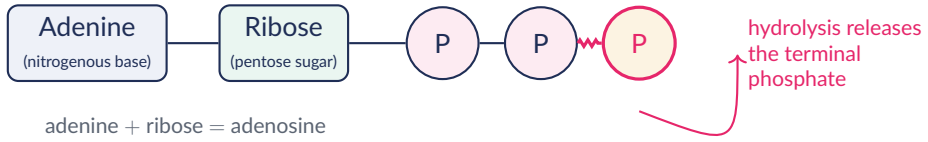
Energy and Respiration

A2 Level

Mục tiêu Unit: ATP là "đồng tiền năng lượng" tức thời của tế bào — cấu trúc, thuỷ phân, và vì sao ATP (chứ không phải glucose) được dùng trực tiếp; bốn giai đoạn hô hấp hiếu khí (đường phân, phản ứng liên kết, chu trình Krebs, photphoryl hoá oxy hoá) cùng vị trí, nguyên liệu và sản phẩm của từng giai đoạn; thuyết hoá thẩm (chemiosmosis) của Peter Mitchell; cách tính sản lượng ATP gần đúng (khoảng 30 ATP/glucose); hô hấp kỵ khí ở động vật và nấm men; hệ số hô hấp (RQ) và cách đo bằng máy đo hô hấp (respirometer).

9.1 ATP: the universal energy currency

Adenosine triphosphate (ATP) is a small, water-soluble nucleotide consisting of three parts: the nitrogenous base **adenine**, the pentose sugar **ribose**, and a chain of **three phosphate groups** attached to the 5′ carbon of ribose. Adenine and ribose together form **adenosine**; adding one, two, or three phosphates gives AMP, ADP, and ATP respectively.



ATP structure: adenine + ribose + three phosphate groups in a chain. The bond linking the terminal (third) phosphate is a relatively unstable, high-energy bond (shown zigzag) that is readily hydrolysed.

ATP hydrolysis and resynthesis

Hydrolysis of the terminal phosphate bond releases the terminal phosphate group as inorganic phosphate (P_i), converting ATP to **ADP**:

$$\text{ATP} + \text{H}_2\text{O} \rightarrow \text{ADP} + \text{P}_i \qquad (\Delta G \approx -30.5 \text{ kJ mol}^{-1} \text{ under standard conditions})$$

This reaction is catalysed by ATP hydrolase (ATPase) enzymes and is directly coupled, at the enzyme's active site, to energy-requiring cellular processes: active transport (pumping ions against a gradient), muscle contraction (myosin cross-bridge cycling), biosynthesis (e.g., dehydration synthesis reactions), nerve impulse transmission (sodium–potassium pump), and cell signalling. Because ATP concentrations in the cell are kept far from equilibrium (products removed quickly, keeping [ATP] high relative to [ADP] and [P_i]), the *actual* free energy released inside a living cell is substantially larger than the standard value, often quoted around 50 kJ mol^{-1}. ATP is continuously regenerated from ADP $+P_i$ using energy released by respiration (or, in autotrophs, also by the light-dependent reactions of photosynthesis) — this ATP/ADP interconversion cycle turns over an enormous number of times per day in an active cell.

Why ATP, not glucose, directly powers most cellular work: (1) ATP hydrolysis releases energy in one small, immediately usable "packet" per reaction, matched to the scale needed by a single enzyme-catalysed step, whereas the complete oxidation of glucose releases a much larger quantity of energy that must be released gradually, in small controlled steps, to avoid being wasted as heat or damaging the cell. (2) ATP hydrolysis is a single, fast, reversible, enzyme-catalysed step that can be tightly coupled directly to a huge range of different reactions across the cell — glucose oxidation cannot be coupled directly in this way. (3) The ATP/ADP system is universal and can be regenerated rapidly and repeatedly, acting as a shuttle/intermediary between energy-releasing (catabolic) and energy-requiring (anabolic) reactions.

VN **GIẢI THÍCH TIẾNG VIỆT**

ATP (adenosine triphosphate) gồm ba phần: bazơ nitơ **adenine**, đường ribose, và **ba nhóm phosphate** nối tiếp nhau. Liên kết giữa phosphate thứ hai và thứ ba là liên kết **cao năng**, khi bị thuỷ phân sẽ giải phóng năng lượng: $\text{ATP} + \text{H}_2\text{O} \rightarrow \text{ADP} + \text{P}_i$. Tế bào không dùng trực tiếp glucose làm nguồn năng lượng cho các phản ứng vì năng lượng trong glucose quá lớn và không thể giải phóng "gọn" trong một bước — trong khi ATP giải phóng năng lượng theo từng "gói nhỏ", vừa đủ cho một phản ứng enzyme, và có thể tái tổng hợp liên tục nhờ hô hấp tế bào. Vì vậy ATP được ví như "tiền lẻ" năng lượng, còn glucose giống như "tài khoản tiết kiệm" dự trữ năng lượng dài hạn.

9.2 Overview of aerobic respiration

Aerobic respiration is the complete oxidation of respiratory substrates (mainly glucose) using oxygen as the final electron acceptor, releasing carbon dioxide and water and yielding a large amount of ATP. It occurs in four linked stages, each in a distinct location within the cell.

Stage	Location	Key inputs	Key outputs (per glucose)
Glycolysis	Cytoplasm (cytosol)	Glucose (6C), 2 ATP, 2 NAD^+	2 pyruvate (3C), net 2 ATP, 2 reduced NAD
Link reaction	Mitochondrial matrix	2 pyruvate, 2 NAD^+, coenzyme A	2 acetyl CoA (2C), 2 CO_2, 2 reduced NAD
Krebs cycle	Mitochondrial matrix	2 acetyl CoA, NAD^+, FAD, ADP $+P_i$	4 CO_2, 6 reduced NAD, 2 reduced FAD, 2 ATP
Oxidative phosphorylation	Inner mitochondrial membrane (cristae)	Reduced NAD, reduced FAD, O_2, ADP $+P_i$	$\approx$26–28 ATP, H_2O (NAD^+/FAD regenerated)

Summary of the four stages of aerobic respiration — location, inputs, and per-glucose outputs.

VN **GIẢI THÍCH TIẾNG VIỆT**

Hô hấp hiếu khí gồm **4 giai đoạn** liên tiếp, mỗi giai đoạn diễn ra ở một vị trí riêng trong tế bào: **đường phân** (tế bào chất — không cần oxy), **phản ứng liên kết** và **chu trình Krebs** (chất nền ti thể), và **photphoryl hoá oxy hoá** (màng trong ti thể, nơi có các nếp gấp *cristae* làm tăng diện tích bề mặt). Ba giai đoạn đầu tạo ra tương đối ít ATP trực tiếp nhưng tích luỹ nhiều **NADH** và **$FADH_2$** — các "phiếu năng lượng" mang electron đến giai đoạn cuối cùng, nơi phần lớn ATP thực sự được tổng hợp.

9.3 Glycolysis

Glycolysis ("sugar splitting") occurs in the cytoplasm of every cell and does not require oxygen. It converts one molecule of glucose (6C) into two molecules of pyruvate (3C) in two phases.

Glycolysis — two phases

Phase 1 — energy investment: glucose is phosphorylated twice (using **2 ATP**), converting it to a more reactive, unstable hexose bisphosphate, which then splits into **two** molecules of triose phosphate (3C each).
Phase 2 — energy payoff: each triose phosphate is oxidised (an electron pair is removed, reducing NAD^+ to **reduced NAD**) and phosphorylated, then converted through several intermediates to **pyruvate**, generating ATP directly by **substrate-level phosphorylation** at two separate steps. Because this happens twice (once for each triose phosphate), phase 2 produces a *gross* yield of 4 ATP and 2 reduced NAD per glucose.
Net yield per glucose: 4 ATP produced $-$ 2 ATP invested $=$ **2 ATP** (net, substrate-level phosphorylation) and **2 reduced NAD (NADH)**, plus **2 pyruvate**.

Net glycolysis summary:

$$\text{glucose} + 2\text{NAD}^+ + 2\text{ADP} + 2\text{P}_i \rightarrow 2\,\text{pyruvate} + 2\,\text{reduced NAD} + 2\text{ATP} + 2\text{H}_2\text{O}$$

Because it occurs in the cytoplasm and needs no oxygen, glycolysis is common to *both* aerobic and anaerobic respiration — it is the one stage every respiring cell always carries out.

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Đường phân chia làm 2 pha: **pha đầu tư năng lượng** (dùng 2 ATP để phosphoryl hoá glucose, sau đó tách thành 2 phân tử triose phosphate 3C) và **pha thu hồi năng lượng** (mỗi triose phosphate bị oxy hoá — khử NAD^+ thành NADH — và tạo ATP trực tiếp qua **phosphoryl hoá mức cơ chất**, cuối cùng tạo pyruvate). Vì có 2 phân tử triose phosphate nên pha thu hồi tạo tổng cộng 4 ATP và 2 NADH; trừ đi 2 ATP đã đầu tư, **lãi ròng chỉ 2 ATP** mỗi glucose. Đường phân xảy ra trong tế bào chất và không cần oxy, nên luôn xảy ra dù tế bào hô hấp hiếu khí hay kỵ khí.

9.4 The link reaction and the Krebs cycle

9.4.1 The link reaction

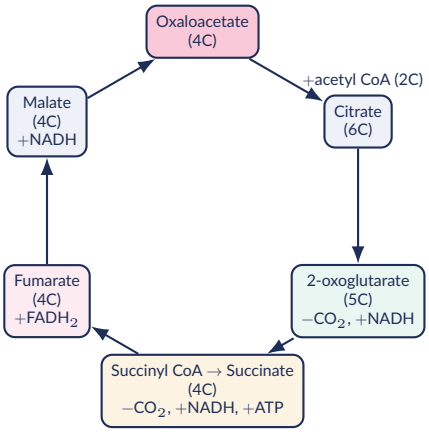
Pyruvate produced by glycolysis is actively transported into the **mitochondrial matrix**. There, each pyruvate (3C) undergoes **oxidative decarboxylation**: it loses a carboxyl group as CO_2 and is oxidised (reducing NAD^+), and the remaining 2C fragment combines with **coenzyme A** to form **acetyl coenzyme A (acetyl CoA)**.

$$\text{pyruvate (3C)} + \text{NAD}^+ + \text{CoA} \rightarrow \text{acetyl CoA (2C)} + \text{CO}_2 + \text{reduced NAD}$$

Since two pyruvate molecules are produced per glucose, the link reaction happens **twice** per glucose, yielding (per glucose) **2 acetyl CoA**, **2 CO_2**, and **2 reduced NAD**.

9.4.2 The Krebs cycle

Acetyl CoA delivers its 2-carbon acetyl group into the **Krebs cycle** (also in the matrix), where it combines with the 4-carbon compound **oxaloacetate** to form the 6-carbon compound **citrate**. A cyclical sequence of oxidation and decarboxylation reactions then regenerates oxaloacetate, ready to accept another acetyl group, while releasing CO_2 and reduced coenzymes.



Simplified Krebs cycle (one turn, one acetyl CoA). Two decarboxylation steps release CO_2; four oxidation steps reduce coenzymes (3 NADH, 1 $FADH_2$); one step produces **1 ATP** directly by substrate-level phosphorylation (via a GTP intermediate). Oxaloacetate is regenerated at the end of each turn.

Krebs cycle — per turn and per glucose

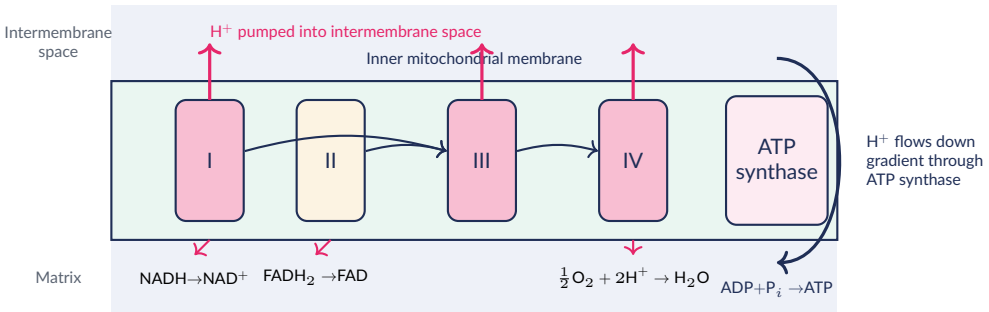
Per turn (per acetyl CoA): 2 CO_2 released, 3 reduced NAD, 1 reduced FAD, 1 ATP (substrate-level phosphorylation).
Per glucose (2 turns, since 2 acetyl CoA enter): 4 CO_2, 6 reduced NAD, 2 reduced FAD, 2 ATP.
Carbon balance check: link reaction releases 2 CO_2 (2 pyruvate → 2 acetyl CoA) and the Krebs cycle releases 4 CO_2 — a total of **6 CO_2**, accounting for all six carbons originally in glucose.

VN **GIẢI THÍCH TIẾNG VIỆT**

Phản ứng liên kết: pyruvate (3C) bị khử carboxyl và oxy hoá thành **acetyl CoA** (2C), giải phóng CO_2 và tạo NADH — xảy ra 2 lần/glucose. **Chu trình Krebs**: acetyl CoA kết hợp với oxaloacetate (4C) tạo citrate (6C); qua một chuỗi phản ứng oxy hoá–khử carboxyl tuần hoàn, oxaloacetate được tái tạo, đồng thời giải phóng CO_2 và tạo NADH, $FADH_2$, và 1 ATP (phosphoryl hoá mức cơ chất) mỗi vòng. Vì có 2 acetyl CoA/glucose nên chu trình quay 2 vòng, tạo tổng cộng 4 CO_2, 6 NADH, 2 $FADH_2$, 2 ATP. Cộng với 2 CO_2 từ phản ứng liên kết, tổng cộng **6 CO_2** được giải phóng — đúng bằng 6 carbon trong 1 phân tử glucose.

9.5 Oxidative phosphorylation and chemiosmosis

The reduced coenzymes (NADH and $FADH_2$) generated by glycolysis, the link reaction, and the Krebs cycle carry high-energy electrons to the **electron transport chain (ETC)**, a series of electron-carrier protein complexes embedded in the **inner mitochondrial membrane** (folded into cristae to maximise surface area).



Electron transport chain and chemiosmosis. Reduced NAD and reduced FAD donate electrons at Complex I / Complex II respectively; as electrons pass along the chain, energy released pumps H^+ from the matrix into the intermembrane

space, creating an electrochemical (proton) gradient. Protons flow back through **ATP synthase**, driving ATP synthesis. At Complex IV, oxygen accepts the (now low-energy) electrons and combines with H^+ to form water.

Chemiosmosis — Peter Mitchell's theory

As electrons pass along the electron transport chain from carrier to carrier (each with a progressively greater affinity for electrons), energy is released at several points and used to actively pump H^+ ions from the matrix into the intermembrane space. Because the inner membrane is largely impermeable to H^+, this builds up a steep **electrochemical (proton) gradient**. Protons can only flow back down this gradient through a specific channel protein, **ATP synthase**; as H^+ flows through it, the enzyme undergoes a conformational change that catalyses $ADP + P_i \rightarrow ATP$. This coupling of an electron transport chain (creating a proton gradient) to ATP synthesis (using that gradient) is called **chemiosmosis**, proposed by **Peter Mitchell** and confirmed as the mechanism of ATP synthesis in both mitochondria and chloroplasts.
Role of oxygen: at the very end of the chain, oxygen acts as the **final electron acceptor**, combining with electrons and H^+ to form water ($\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$). Without oxygen, electrons cannot leave the chain; every carrier remains in its reduced form, the whole chain "backs up" and stops, NAD^+/FAD cannot be regenerated, no more H^+ can be pumped, the gradient collapses, and ATP synthase stops working almost entirely — eliminating the vast majority of ATP production.

VN **GIẢI THÍCH TIẾNG VIỆT**
Chuỗi truyền electron nằm ở màng trong ti thể: NADH và $FADH_2$ nhường electron cho chuỗi, năng lượng giải phóng khi electron di chuyển được dùng để **bơm H^+** từ chất nền ra khoang giữa hai màng, tạo **gradient điện hoá**. H^+ chỉ có thể khuếch tán ngược trở lại qua kênh **ATP synthase**, và dòng H^+ này làm enzyme thay đổi hình dạng để tổng hợp ATP từ $ADP + P_i$ — cơ chế này gọi là **hoá thẩm (chemiosmosis)**, do Peter Mitchell đề xuất. Oxy là **chất nhận electron cuối cùng**, kết hợp với electron và H^+ để tạo nước; nếu thiếu oxy, chuỗi truyền electron "tắc nghẽn" hoàn toàn, gradient H^+ mất đi, và ATP synthase ngừng hoạt động — đây là lý do vì sao thiếu oxy làm ngừng gần như toàn bộ quá trình tổng hợp ATP.

(!) Lỗi thường gặp: Nhiều học sinh nghĩ NADH và $FADH_2$ tạo ra **cùng** một lượng ATP. Thực ra $FADH_2$ nhường electron vào chuỗi ở một điểm **muộn hơn, năng lượng thấp hơn** so với NADH, nên bơm được ít H^+ hơn và tạo **ít ATP hơn** mỗi phân tử so với NADH (theo tỉ lệ gần đúng hiện nay: khoảng 2.5 ATP/NADH so với khoảng 1.5 ATP/$FADH_2$).

9.6 ATP yield: an approximate accounting

Older textbooks quoted a fixed total of **38 ATP** per glucose, assuming exactly 3 ATP per NADH and 2 ATP per $FADH_2$ with no additional costs. Modern biochemistry recognises the yield is not a fixed whole number: reduced coenzymes deliver closer to **≈2.5 ATP per NADH** and **≈1.5 ATP per $FADH_2$** through ATP synthase, and — critically — the 2 NADH produced by glycolysis are made in the *cytoplasm*, but the electron transport chain is inside the mitochondrion; shuttling those electrons across the mitochondrial membrane costs some of the proton gradient (via the glycerol phosphate shuttle, effectively costing ≈1.5 ATP each) or is nearly free (via the malate–aspartate shuttle, ≈2.5 ATP each, used in liver, heart, and kidney cells). Combining these figures gives an approximate theoretical maximum yield of about **30 ATP** per glucose (commonly cited as ≈30–32, depending on which shuttle is used).

Source	Reduced coenzyme	Approx. ATP	Notes
Glycolysis (substrate-level)	—	2	Net, cytoplasm
Glycolysis NADH ($\times 2$)	2 NADH	≈3–5	Cost of shuttle across mitochondrial membrane
Link reaction NADH ($\times 2$)	2 NADH	≈5	2×2.5
Krebs cycle (substrate-level)	—	2	Direct, matrix
Krebs cycle NADH ($\times 6$)	6 NADH	≈15	6×2.5
Krebs cycle $FADH_2$ ($\times 2$)	2 $FADH_2$	≈3	2×1.5
Approximate total		**≈30**	Theoretical maximum, per glucose

Approximate ATP accounting per glucose molecule. Actual measured yields are usually somewhat lower, since some of the proton gradient is used for other purposes (transporting pyruvate and P_i into the matrix) and some protons "leak" back across the membrane without passing through ATP synthase (proton leak), dissipating the gradient as heat rather than ATP.

VN **GIẢI THÍCH TIẾNG VIỆT**

Trước đây sách giáo khoa hay ghi cố định **38 ATP**/glucose, nhưng con số này giả định mỗi NADH luôn tạo đúng 3 ATP và mỗi $FADH_2$ tạo đúng 2 ATP, không tính chi phí vận chuyển NADH từ tế bào chất vào ti thể. Số liệu hiện đại cho thấy tỉ lệ thực tế gần đúng là **2.5 ATP/-NADH** và **1.5 ATP/$FADH_2$**, cộng thêm việc 2 NADH sinh ra từ đường phân phải "tốn phí" để vận chuyển qua màng ti thể — vì vậy tổng sản lượng ATP thực tế trên lý thuyết vào khoảng **30 ATP**/glucose, và có thể còn thấp hơn do rò rỉ proton (proton leak) hoặc năng lượng dùng cho các mục đích vận chuyển khác qua màng.

9.7 Anaerobic respiration

When oxygen is unavailable, the electron transport chain cannot function (no final electron acceptor), so NAD^+ cannot be regenerated by oxidative phosphorylation. Since glycolysis requires a continuous supply of NAD^+ to keep oxidising triose phosphate, cells must regenerate NAD^+ by another route: reducing pyruvate.

Two forms of anaerobic respiration

In mammals (lactate/lactic acid fermentation):

$$\text{pyruvate} + \text{reduced NAD} \rightarrow \text{lactate} + NAD^+$$

This regenerates NAD^+, allowing glycolysis to continue producing ATP without oxygen. Net yield: only the **2 ATP** from glycolysis (no further ATP is produced from lactate formation itself).
In yeast and plants (alcoholic fermentation):

$$\text{pyruvate} \rightarrow \text{ethanal} + CO_2 \qquad \text{ethanal} + \text{reduced NAD} \rightarrow \text{ethanol} + NAD^+$$

Pyruvate is first decarboxylated to ethanal (releasing CO_2), then ethanal is reduced to **ethanol**, regenerating NAD^+. Net yield: again only **2 ATP** per glucose.

Anaerobic respiration yields far less ATP than aerobic respiration (2 vs. ≈30 ATP per glucose) because the vast majority of the chemical potential energy in glucose remains locked within lactate or ethanol — without an electron transport chain and oxygen as a powerful final electron acceptor, that energy cannot be harvested as ATP. Anaerobic respiration is therefore only a short-term, emergency measure (e.g., in vigorously contracting skeletal muscle during intense exercise) rather than a sustainable long-term energy source.

Feature	Aerobic respiration	Anaerobic respiration
Oxygen required	Yes	No
Location	Cytoplasm + mitochondria	Cytoplasm only
End product(s)	$CO_2 + H_2O$	Lactate (mammals) or ethanol + CO_2 (yeast/plants)
Approx. ATP/glucose	≈30	2
Glucose oxidised	Completely	Only partially
Krebs cycle / ETC used	Yes	No

Aerobic vs. anaerobic respiration — key comparison points.

VN **GIẢI THÍCH TIẾNG VIỆT**

Khi thiếu oxy, chuỗi truyền electron ngừng hoạt động nên NAD^+ không được tái tạo bằng con đường photphoryl hoá oxy hoá. Vì đường phân cần NAD^+ liên tục để tiếp tục hoạt động, tế bào phải tái tạo NAD^+ bằng cách **khử pyruvate**: ở động vật có vú, pyruvate → **lactate**; ở nấm men/thực vật, pyruvate → **ethanol** + CO_2. Cả hai con đường đều chỉ thu được **2 ATP**/glucose (từ đường phân) vì phần lớn năng lượng hoá học vẫn còn "khoá" trong lactate/ethanol chưa được giải phóng hết.

9.8 Respiratory substrates and the respiratory quotient (RQ)

Different respiratory substrates (carbohydrate, lipid, protein) require different relative amounts of oxygen to be completely oxidised, because they differ in the ratio of hydrogen and oxygen atoms already present per carbon atom. The **respiratory quotient (RQ)** compares the volume of CO_2 produced to the volume of O_2 consumed in the same time period:

$$\text{RQ} = \frac{\text{volume of } CO_2 \text{ produced}}{\text{volume of } O_2 \text{ consumed}}$$

(Equivalently, moles of CO_2 / moles of O_2, since equal volumes of gas at the same temperature and pressure contain equal numbers of moles.)

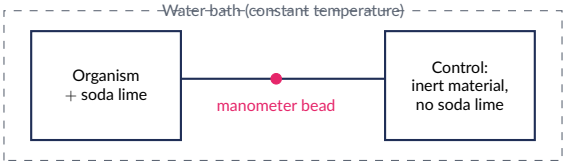
Substrate	Typical RQ	Reason
Carbohydrate (e.g., glucose)	≈ 1.0	$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ — equal moles of CO_2 produced and O_2 consumed
Lipid (fat)	≈ 0.7	Fatty acids have a much higher ratio of H to O per carbon than carbohydrate, so more O_2 is needed per carbon to fully oxidise all that extra hydrogen to water; CO_2 output per O_2 consumed is therefore lower
Protein	≈ 0.9 (approximate)	Amino acids contain nitrogen (excreted, not fully oxidised to CO_2/H_2O), giving an intermediate, less clean-cut value

Typical RQ values by respiratory substrate.

(!) Lỗi thường gặp: RQ > 1 is possible: it can occur during vigorous exercise, or when carbohydrate is being converted into fat (lipogenesis, which releases extra CO_2 without consuming corresponding O_2), or when anaerobic respiration is occurring alongside aerobic respiration (extra CO_2 from the small aerobic component while very little O_2 is consumed by the anaerobic component). Never assume RQ > 1 is "impossible" or a measurement error.

9.8.1 Measuring respiration: the respirometer

A simple **respirometer** measures the rate of oxygen uptake by a small organism (e.g., germinating seeds, insects, small invertebrates). The organism is placed in a sealed tube connected via a capillary tube (containing a coloured liquid manometer bead, or connected to a syringe) to a second, identical tube. **Soda lime** (or KOH solution) is placed in the tube with the organism to absorb all CO_2 produced, so that any change in gas volume/pressure reflects *only* O_2 consumption. A second, **control tube** — identical in every way but containing an inert object of similar volume instead of a living organism, and no soda lime — corrects for changes in gas volume caused by fluctuations in atmospheric temperature or pressure during the experiment (which would otherwise be wrongly attributed to the organism's respiration).



A simple respirometer: soda lime absorbs CO_2 from the organism's tube so the manometer bead moves only in response to O_2 uptake; the control tube (no organism, no soda lime) corrects for changes in temperature/pressure unrelated to respiration. The whole apparatus is kept in a water bath at constant temperature to minimise this correction.

VN **GIẢI THÍCH TIẾNG VIỆT**

RQ = thể tích CO_2 thải ra ÷ thể tích O_2 hấp thụ, trong cùng thời gian. Carbohydrate cho RQ ≈ 1.0 (số mol CO_2 tạo ra bằng số mol O_2 tiêu thụ); lipid cho RQ ≈ 0.7 vì acid béo có tỉ lệ H/O trên mỗi carbon cao hơn nhiều, cần nhiều O_2 hơn để oxy hoá hết lượng H dư; protein cho RQ ≈ 0.9 (giá trị gần đúng) vì chứa nitơ không được oxy hoá hoàn toàn thành CO_2/H_2O. **Máy đo hô hấp (respirometer)** dùng vôi tôi xút (soda lime) để hấp thụ CO_2 sinh vật thải ra, khi đó sự thay đổi thể tích/áp suất trong ống chỉ phản ánh lượng O_2 tiêu thụ; một **ống đối chứng** (không có sinh vật, không có soda lime) giúp hiệu chỉnh sai số do nhiệt độ/áp suất phòng thay đổi trong lúc đo.

9.9 Worked examples

RQ calculation — carbohydrate substrate

A germinating pea seed consumes 420 mm^3 of O_2 and produces 410 mm^3 of CO_2 in 20 minutes. Calculate the RQ and identify the likely respiratory substrate.

$$\text{RQ} = \frac{410}{420} = 0.976 \approx 1.0$$

An RQ close to 1.0 indicates the seed is respiring mainly **carbohydrate** (stored starch reserves), consistent with the complete oxidation $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$, which consumes and produces equal molar (hence volume) amounts of gas.

RQ calculation — lipid substrate

A germinating oil-storing seed (e.g., castor bean) is found to consume 860 mm^3 of O_2 and produce 600 mm^3 of CO_2 over the same time period. Calculate the RQ and comment.

$$\text{RQ} = \frac{600}{860} = 0.698 \approx 0.70$$

This RQ is characteristic of **lipid** respiration. Fatty acid chains carry a much higher proportion of hydrogen relative to oxygen (and carbon) than carbohydrate does, so oxidising them fully to CO_2 and H_2O requires proportionally more O_2 per CO_2 released — lowering the RQ well below 1.0. This matches the seed's use of stored oil (triglyceride) reserves during early germination.

Interpreting a mixed/changing RQ

Over several days of germination, a seed's RQ is measured as: Day 1, RQ $= 0.72$; Day 4, RQ $= 0.90$; Day 8, RQ $= 1.0$. Suggest an explanation for this trend.

The rising RQ suggests a shift in respiratory substrate over time: initially (**Day 1**) the seed relies mainly on stored **lipid** reserves (RQ ≈ 0.7); by **Day 4** a mixture of lipid and protein/carbohydrate is used (intermediate RQ); by **Day 8**, once the seedling has developed leaves and begun photosynthesising, it relies increasingly on newly synthesised **carbohydrate** (RQ $\to 1.0$). This is a common pattern in oil-storing seeds such as sunflower or castor bean.

Respirometer volume-change calculation with control correction

In a respirometer experiment at constant temperature, the manometer bead in the tube containing woodlice moves through 48 mm^3 towards the organism's tube in 10 minutes. In the control tube (no organism, no soda lime), the bead moves 6 mm^3 *away* from the control tube over the same period (due to a small rise in room temperature). Calculate the corrected rate of oxygen uptake.

The bead moving toward the organism's tube indicates a decrease in gas volume there — consistent with O_2 being absorbed (and CO_2 removed by soda lime). The control's movement (bead moving away from the control, i.e., gas in the control expanding) shows that rising temperature alone would cause an apparent *increase* in volume of 6 mm^3 in the experimental tube too, partially masking the true O_2 uptake.

$$\text{True } O_2 \text{ uptake} = 48 + 6 = 54 \text{ mm}^3 \text{ in 10 minutes}$$

$$\text{Rate} = \frac{54 \text{ mm}^3}{10 \text{ min}} = 5.4 \text{ mm}^3 \text{ min}^{-1}$$

ATP yield accounting per stage

For one molecule of glucose respired aerobically, tabulate the net ATP directly produced by substrate-level phosphorylation only (excluding oxidative phosphorylation), and state what fraction of the total approximate yield (≈30 ATP) this represents.

Substrate-level phosphorylation occurs in glycolysis (net 2 ATP) and the Krebs cycle (2 ATP, since the cycle turns twice per glucose) = **4 ATP total** directly. As a fraction of the total approximate yield: $4/30 \approx 13\%$. The remaining $\approx 87\%$ of ATP is generated indirectly, via oxidative phosphorylation (chemiosmosis) using the reduced NAD and reduced FAD carried to the elec-

tron transport chain.

Distinguishing aerobic from anaerobic respiration using experimental data

A yeast culture is monitored in a closed flask. For the first 30 minutes, O_2 concentration in the flask falls steadily and CO_2 concentration rises at a matching rate. After 30 minutes, O_2 concentration reaches zero and stays at zero, but CO_2 concentration continues to rise steadily. Explain this pattern.

During the first 30 minutes, the yeast is respiring **aerobically** (O_2 consumed, CO_2 produced at a comparable rate, consistent with an RQ near 1.0 for a carbohydrate substrate). Once O_2 is fully depleted (available oxygen is exhausted in the closed flask), the yeast switches to **anaerobic (alcoholic) fermentation**: pyruvate $\rightarrow$ ethanal $+$ CO_2, then ethanal $\rightarrow$ ethanol (regenerating NAD^+). This still releases CO_2 (from the decarboxylation step) even though no O_2 is being consumed — explaining why CO_2 output continues after O_2 uptake has stopped completely.

Interpreting a labelled respirometer diagram

In a respirometer set-up, the experimental tube (organism $+$ soda lime) and control tube (glass bead, no soda lime) are connected to a scale reading in mm^3. Over 15 minutes at $20\,^\circ\text{C}$, the manometer reading in the experimental tube changes by -63 mm^3 and in the control by $+3$ mm^3. Calculate the rate of O_2 consumption in $\text{mm}^3\,\text{h}^{-1}$.

Corrected change $= -63 - (+3) = -66$ mm^3 (the negative sign confirms a net decrease in gas volume, i.e. O_2 uptake) over 15 minutes.

$$\text{Rate} = \frac{66\ \text{mm}^3}{15\ \text{min}} \times 60 = 264\ \text{mm}^3\,\text{h}^{-1}$$

Effect of a metabolic poison on ATP yield

Dinitrophenol (DNP) is a chemical that makes the inner mitochondrial membrane "leaky" to protons, allowing H^+ to cross back into the matrix *without* passing through ATP synthase. Predict the effect on (a) oxygen consumption and (b) ATP yield, and explain your reasoning.

(a) Oxygen consumption **increases** — the electron transport chain speeds up as it tries to keep pumping H^+ out to maintain the (now constantly leaking) gradient, so more electrons flow through the chain and more O_2 is used as the final electron acceptor. (b) ATP yield **falls** — because H^+ re-enters the matrix through the membrane itself rather than through ATP synthase, the proton-motive force is "short-circuited" and much less of it drives ATP synthesis; the energy is instead released as heat. (This is, in fact, how DNP was historically — and dangerously — used as a weight-loss drug: it uncouples respiration from ATP production, wasting food energy as heat.)

Calculating O_2 consumption rate from bubble/manometer data over changing time intervals

A respirometer records the following cumulative O_2 uptake by a locust at rest: 0 min $\rightarrow$ 0 mm^3; 10 min $\rightarrow$ 22 mm^3; 20 min $\rightarrow$ 46 mm^3; 30 min $\rightarrow$ 69 mm^3. Calculate the mean rate of O_2 consumption over the 30 minutes, and comment on whether the rate is constant.

Mean rate $= 69$ $\text{mm}^3 \div 30$ min $= 2.3$ $\text{mm}^3\,\text{min}^{-1}$. Checking successive 10-minute intervals:

$22, 24, 23$ mm^3 — very close to constant (≈ 2.2–2.4 mm^3 min^{-1} each interval), suggesting the locust's resting metabolic rate is approximately steady over this period.

9.10 Practice bank

Bài tập luyện tập

Which three components make up an ATP molecule?

(A) Adenine, deoxyribose, three phosphate groups
(B) Adenine, ribose, three phosphate groups
(C) Guanine, ribose, two phosphate groups
(D) Adenine, ribose, one phosphate group

Lời giải chi tiết

ATP = adenine (base) + **ribose** (not deoxyribose — ATP is a ribonucleotide) + **three** phosphate groups. **(B)**.

Bài tập luyện tập

Explain, in terms of energy release, why ATP rather than glucose is used directly to power most energy-requiring reactions in cells.

Lời giải chi tiết

Complete oxidation of glucose releases a large amount of energy in total, but this is far more than any single enzyme-catalysed reaction needs — releasing it all at once in one step would waste most of it as heat (and could damage the cell). ATP hydrolysis, by contrast, releases a small, controlled "packet" of energy per reaction, well matched to the requirements of a single coupled reaction. ATP hydrolysis is also a single fast reversible step that many different enzymes can couple directly to, whereas glucose oxidation cannot be coupled directly to arbitrary reactions; and ATP can be rapidly regenerated from ADP + P_i, acting as a continuously-recycled energy intermediary between catabolic and anabolic reactions.

Bài tập luyện tập

State the location in the cell where glycolysis occurs, and give the net ATP and reduced NAD yield per glucose molecule.

Lời giải chi tiết

Glycolysis occurs in the **cytoplasm (cytosol)**. Net yield per glucose: **2 ATP** (net, by substrate-level phosphorylation) and **2 reduced NAD**, plus 2 pyruvate molecules.

Bài tập luyện tập

During glycolysis, why is an initial investment of 2 ATP required before any ATP is generated?

(A) To provide the activation energy that destabilises glucose and its intermediates, making the later energy-releasing steps possible

(B) Because glucose cannot enter the cytoplasm without being phosphorylated first

(C) To directly power the Krebs cycle

(D) ATP is not actually invested — this is a common misconception

Lời giải chi tiết

Phosphorylating glucose (and its 6-carbon derivative) adds phosphate groups that destabilise the molecule and prime it for splitting into two triose phosphate molecules; this investment makes the subsequent energy-releasing (payoff) phase, which generates more ATP and reduced NAD, possible. **(A)**.

Bài tập luyện tập

Name the products of the link reaction (per pyruvate molecule) and state its location.

Lời giải chi tiết

Location: **mitochondrial matrix**. Per pyruvate: pyruvate is decarboxylated (releasing **CO_2**) and oxidised (reducing NAD^+ to **reduced NAD**), and the remaining 2-carbon acetyl group combines with coenzyme A to form **acetyl coenzyme A**.

Bài tập luyện tập

Per turn of the Krebs cycle (one acetyl CoA), how many molecules of CO_2, reduced NAD, reduced FAD, and ATP are produced?

(A) 1 CO_2, 1 reduced NAD, 1 reduced FAD, 1 ATP

(B) 2 CO_2, 3 reduced NAD, 1 reduced FAD, 1 ATP

(C) 2 CO_2, 1 reduced NAD, 3 reduced FAD, 2 ATP

(D) 3 CO_2, 2 reduced NAD, 2 reduced FAD, 1 ATP

Lời giải chi tiết

One turn of the Krebs cycle produces **2 CO_2**, **3 reduced NAD**, **1 reduced FAD**, and **1 ATP** (via substrate-level phosphorylation). **(B)**.

Bài tập luyện tập

Explain why the total CO_2 released per glucose molecule during aerobic respiration is exactly 6, and identify precisely where each CO_2 is released.

Lời giải chi tiết

Glucose has 6 carbon atoms; every one is eventually released as CO_2. Per glucose: the link reaction occurs twice (once per pyruvate), releasing **2 CO_2**; the Krebs cycle turns twice (once per acetyl CoA), releasing **2 CO_2 per turn** $\times 2 =$ **4 CO_2**. Total: $2 + 4 =$ **6 CO_2**, accounting for all six carbons of the original glucose molecule (glycolysis itself releases no CO_2).

Bài tập luyện tập

What is the immediate function of oxygen in aerobic respiration?

(A) It combines directly with glucose in glycolysis

(B) It acts as the final electron acceptor in the electron transport chain, combining with electrons and H^+ to form water

(C) It is used to synthesise ATP directly, without any electron transport chain

(D) It regenerates FAD in the Krebs cycle only

Lời giải chi tiết

Oxygen is the final electron acceptor at the end of the electron transport chain (Complex IV), combining with low-energy electrons and H^+ to form water; this keeps the chain flowing (regenerating NAD^+/FAD from NADH/$FADH_2$ throughout). **(B)**.

Bài tập luyện tập

Describe, in the correct sequence, how a proton gradient generated by the electron transport chain leads to ATP synthesis (chemiosmosis).

Lời giải chi tiết

Electrons pass along the carriers of the electron transport chain, releasing energy at several points; this energy is used to actively pump H^+ ions from the mitochondrial matrix into the intermembrane space, against their concentration gradient. Because the inner membrane is largely impermeable to H^+, this builds a steep electrochemical (proton) gradient. H^+ can only diffuse back down this gradient through the channel protein **ATP synthase**; the resulting flow of protons through the enzyme drives a conformational change that catalyses the synthesis of ATP from ADP $+P_i$. This whole process — an electron transport chain generating a gradient that is then used by ATP synthase — is called chemiosmosis.

Bài tập luyện tập

A poison specifically inhibits ATP synthase (but does not affect the electron transport chain carriers themselves). Predict the immediate effect on (a) the size of the proton gradient and (b) electron flow along the chain, with reasoning.

Lời giải chi tiết

(a) The proton gradient **increases** initially — H^+ continues to be pumped out by the chain but can no longer flow back through ATP synthase (since it is blocked), so H^+ accumulates in the intermembrane space. (b) Electron flow along the chain **slows and eventually stops** — as the proton gradient becomes very steep, it becomes energetically much harder to pump further H^+ against such a strong gradient (a "back-pressure" effect), so the whole chain backs up even though ATP synthase itself, not the chain, was the direct target.

Bài tập luyện tập

Approximately how many ATP molecules are now considered to be produced per glucose molecule in aerobic respiration, and why is this figure lower than the historically-quoted value of 38?

Lời giải chi tiết

Approximately **30 ATP** per glucose (commonly cited as ≈30–32). The older figure of 38 assumed a fixed ratio of exactly 3 ATP per NADH and 2 ATP per $FADH_2$, with no cost for transporting cytoplasmic NADH into the mitochondrion. Modern measurements show the true ratios are closer to ≈2.5 ATP/NADH and ≈1.5 ATP/$FADH_2$, and that shuttling the 2 NADH produced by glycolysis across the mitochondrial membrane consumes some of the proton gradient. Additional variability comes from proton leak across the membrane and use of the gradient for other transport processes.

Bài tập luyện tập

Give one reason why the actual measured ATP yield per glucose in a living cell might be even lower than the theoretical maximum of ≈30.

(A) Some protons leak back across the inner mitochondrial membrane without passing through ATP synthase, dissipating the gradient as heat

(B) Glycolysis always produces exactly 38 ATP regardless of conditions

(C) Oxygen is never actually used as the final electron acceptor

(D) The Krebs cycle only occurs once per glucose molecule

Lời giải chi tiết

Proton leak across the membrane wastes part of the electrochemical gradient as heat instead of driving ATP synthase, lowering the actual ATP yield below the theoretical maximum. **(A)**.

Bài tập luyện tập

State the two products of lactate fermentation in mammalian muscle cells, and explain its main biochemical purpose.

Lời giải chi tiết

Products: **lactate** and **NAD^+**, from the reaction pyruvate + reduced NAD → lactate + NAD^+. Its main purpose is to regenerate NAD^+, which is required by glycolysis (at the oxidation step converting triose phosphate towards pyruvate); without regenerating NAD^+, the limited cytoplasmic pool of NAD^+ would be quickly used up, and glycolysis (the cell's only remaining source of ATP without oxygen) would stop.

Bài tập luyện tập

Yeast cells respiring anaerobically produce ethanol and carbon dioxide. Write the two-step conversion of pyruvate to ethanol and identify which step regenerates NAD^+.

Lời giải chi tiết

Step 1: pyruvate → ethanal + CO_2 (decarboxylation). Step 2: ethanal + reduced NAD → ethanol + NAD^+ (reduction). **Step 2** regenerates NAD^+, allowing glycolysis to continue.

Bài tập luyện tập

Explain, using approximate ATP figures, why anaerobic respiration is described as a "short-term" solution rather than a sustainable energy source for an active muscle.

Lời giải chi tiết

Anaerobic respiration yields only about **2 ATP** per glucose (from glycolysis alone), compared to roughly **30 ATP** per glucose from aerobic respiration — around 15 times less energy extracted from the same amount of glucose. To sustain the same rate of ATP supply anaerobically, a muscle would need to consume glucose roughly 15 times faster, rapidly depleting glycogen stores; additionally, lactate accumulation contributes to a fall in intracellular pH, impairing enzyme function and contributing to muscle fatigue. Anaerobic respiration is therefore only sustainable briefly, until oxygen supply catches up (repaying the "oxygen debt").

Bài tập luyện tập

An investigator measures O_2 consumption and CO_2 production of a small mammal and finds RQ $= 0.85$. What does this suggest about its diet/respiratory substrate at the time of measurement?

(A) Respiring pure carbohydrate only

(B) Respiring pure lipid only

(C) Respiring a mixture of substrates, likely including a significant proportion of protein and/or lipid alongside carbohydrate

(D) The measurement must be an error, since RQ cannot be between 0.7 and 1.0

Lời giải chi tiết

An RQ of 0.85 lies between the values typical of pure carbohydrate (≈ 1.0) and pure lipid (≈ 0.7)/protein (≈ 0.9), suggesting the animal is respiring a **mixture** of substrates rather than one exclusively. **(C)**.

Bài tập luyện tập

A respiring organism consumes 250 mm^3 of O_2 and produces 175 mm^3 of CO_2 in 15 minutes. Calculate the RQ and identify the most likely respiratory substrate.

Lời giải chi tiết

$$\text{RQ} = \frac{175}{250} = 0.70$$

An RQ of 0.70 indicates the organism is respiring predominantly **lipid**.

Bài tập luyện tập

A respiring organism produces 540 mm^3 of CO_2 and consumes 540 mm^3 of O_2 in 12 minutes. Calculate the RQ, and explain in molecular terms why this value is expected for this substrate.

Lời giải chi tiết

$$\text{RQ} = \frac{540}{540} = 1.0$$

An RQ of 1.0 is expected for **carbohydrate** respiration: the balanced equation $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ shows that exactly 6 moles of CO_2 are produced for every 6 moles of O_2 consumed — a 1:1 ratio — because glucose already contains oxygen atoms in a ratio that, combined with the O_2 consumed, exactly balances the CO_2 and H_2O produced.

Bài tập luyện tập

Explain, in terms of chemical composition, why lipids give a lower RQ than carbohydrates.

Lời giải chi tiết

Fatty acid chains (the major component of lipids) contain a much higher proportion of hydrogen atoms relative to oxygen atoms per carbon than carbohydrates do (carbohydrates already have an approximately 2:1 H:O ratio matching water, CH_2O). Oxidising the "extra" hydrogen atoms in fatty acids to form water requires additional O_2 beyond what is needed to convert the carbon skeleton to CO_2. This means more O_2 must be consumed per CO_2 produced when oxidising lipid, giving a lower RQ (volume CO_2/volume O_2) of around 0.7.

Bài tập luyện tập

State two functions of soda lime in a respirometer experiment, and one function of the control tube.

Lời giải chi tiết

Soda lime: (1) absorbs the CO_2 produced by the respiring organism, so that any change in gas volume/pressure in the tube reflects only O_2 consumption (not the balancing effect of CO_2 released); this allows O_2 uptake to be measured directly and unambiguously. Control tube: corrects for changes in gas volume caused by fluctuations in atmospheric temperature or pressure during the experiment (which affect both tubes equally but are unrelated to respiration), allowing these to be subtracted out to leave only the true, respiration-driven change.

Bài tập luyện tập

In a respirometer experiment, the experimental tube (organism + soda lime) shows a volume decrease of 72 mm^3 over 12 minutes, while the control tube shows a volume increase of 8 mm^3 over the same period (due to rising room temperature). Calculate the corrected rate of O_2 consumption in mm^3 min^{-1}.

Lời giải chi tiết

The control's $+8$ mm^3 increase shows that temperature alone would cause the experimental tube's volume to rise by 8 mm^3 too, partially offsetting the true O_2 uptake. Corrected decrease $= 72 + 8 = 80$ mm^3.

$$\text{Rate} = \frac{80 \text{ mm}^3}{12 \text{ min}} \approx 6.7 \text{ mm}^3 \text{ min}^{-1}$$

Bài tập luyện tập

A student sets up a respirometer with germinating peas at $25\,^{\circ}$C and repeats the experiment with the same mass of germinating peas at $15\,^{\circ}$C. Predict and explain the expected difference in the rate of O_2 uptake.

Lời giải chi tiết

The rate of O_2 uptake will be **higher at** $25\,^{\circ}$C than at $15\,^{\circ}$C. Respiration is enzyme-controlled (e.g., the enzymes of glycolysis, the link reaction, Krebs cycle); within the normal physiological range, increasing temperature increases the kinetic energy of molecules, raising the frequency of successful enzyme–substrate collisions and hence the rate of these enzyme-catalysed reactions, increasing overall respiration rate and O_2 demand. (If temperature were raised too high, enzymes would begin to denature and the rate would fall — but $25\,^{\circ}$C is within the normal operating range for pea seedlings.)

Bài tập luyện tập

Why must a respirometer experiment ideally be conducted inside a water bath at constant temperature, even when a control tube is used?

(A) Water baths are only needed for aesthetic reasons

(B) A water bath minimises temperature fluctuations in the first place, reducing the size of the correction needed and making the control tube's correction more reliable, since large sudden temperature swings might not affect both tubes identically

(C) The organism needs to be kept underwater to respire

(D) Soda lime only works underwater

Lời giải chi tiết

Although the control tube corrects for temperature/pressure changes, this correction works best when changes are small and gradual and affect both tubes equally; a constant-temperature water bath reduces the size and rate of any temperature fluctuation, minimising the correction required and improving the reliability and precision of the O_2 uptake measurement. **(B)**.

Bài tập luyện tập

A locust is respiring aerobically at rest, consuming O_2 at 2.0 mm^3 min^{-1}. Assuming an RQ of 0.85 for its current mixed diet, calculate its rate of CO_2 production.

Lời giải chi tiết

$\text{RQ} = \text{CO}_2/\text{O}_2 \Rightarrow \text{CO}_2 = \text{RQ} \times \text{O}_2 = 0.85 \times 2.0 = 1.7$ mm^3 min^{-1}.

Bài tập luyện tập

Explain why glycolysis is described as occurring in "every respiring cell," regardless of whether that cell is respiring aerobically or anaerobically.

Lời giải chi tiết

Glycolysis takes place in the cytoplasm and does not require oxygen at any step — it converts glucose to pyruvate using only cytoplasmic enzymes, ATP, and NAD^+. Whether the cell subsequently has oxygen available (and proceeds to the link reaction, Krebs cycle, and oxidative phosphorylation) or not (and instead regenerates NAD^+ via lactate or alcoholic fermentation), glycolysis itself proceeds identically as the first, universal stage of respiration.

Bài tập luyện tập

Cyanide binds irreversibly to the final complex of the electron transport chain (Complex IV), preventing electrons from being passed to oxygen. Predict and explain the effect on the rate of the Krebs cycle within minutes of cyanide poisoning.

Lời giải chi tiết

The rate of the Krebs cycle falls sharply and eventually stops. Blocking Complex IV prevents electrons from leaving the chain, so all upstream carriers (and eventually NAD^+/FAD) remain in their reduced form and cannot accept further electrons from the Krebs cycle's dehydrogenase reactions. Since the Krebs cycle requires a continuous supply of oxidised NAD^+ and FAD to keep running (several of its steps are oxidation reactions), and these can no longer be regenerated once the chain is blocked, the Krebs cycle grinds to a halt even though cyanide does not act on the Krebs cycle enzymes directly.

Bài tập luyện tập

Compare the number of ATP produced by substrate-level phosphorylation versus oxidative phosphorylation per glucose molecule, and explain which process contributes the larger share of the total approximate yield.

Lời giải chi tiết

Substrate-level phosphorylation (glycolysis + Krebs cycle) produces **4 ATP** directly per glucose. Oxidative phosphorylation (via the electron transport chain and chemiosmosis, using the reduced NAD and FAD generated) produces the remaining ≈**26 ATP** of the total ≈30. Oxidative phosphorylation therefore contributes the much larger share ($\approx 87\%$) because it can extract energy from the ten NADH and two $FADH_2$ molecules generated across all three earlier stages, each yielding several ATP via the proton gradient, rather than the single direct phosphate-transfer events of substrate-level phosphorylation.

Bài tập luyện tập

A cell is treated with a drug that specifically blocks coenzyme A synthesis. Predict the immediate effect on the Krebs cycle and explain your reasoning.

(A) No effect, since coenzyme A is not required for the Krebs cycle

(B) The Krebs cycle stops, because acetyl CoA (formed using coenzyme A in the link reaction) cannot be produced to feed the cycle

(C) Glycolysis stops instead

(D) Oxidative phosphorylation increases to compensate

Lời giải chi tiết

Blocking coenzyme A synthesis prevents the link reaction from producing acetyl CoA (pyruvate cannot combine with CoA), so no acetyl groups can enter the Krebs cycle, which therefore stops turning (though existing intermediates may allow a few more turns until oxaloacetate/citrate pools are exhausted). **(B)**.

Bài tập luyện tập

Distinguish between substrate-level phosphorylation and oxidative phosphorylation, giving one example of where each occurs.

Lời giải chi tiết

Substrate-level phosphorylation: a phosphate group is transferred directly from a phosphorylated intermediate substrate molecule to ADP, forming ATP, without involvement of the electron transport chain or a proton gradient — e.g., in glycolysis (phosphoglycerate kinase step) or the Krebs cycle (succinyl CoA → succinate step). **Oxidative phosphorylation**: ATP synthesis is driven indirectly by a proton gradient generated by the electron transport chain (chemiosmosis) — occurs at ATP synthase in the inner mitochondrial membrane, using energy ultimately derived from oxidising NADH/$FADH_2$ with O_2 as final electron acceptor.

Bài tập luyện tập

An athlete's muscle RQ is measured as 1.3 immediately after a maximal sprint. Suggest an explanation for this unusually high value.

Lời giải chi tiết

An RQ above 1.0 during intense anaerobic exercise can occur because CO_2 continues to be released from the small amount of ongoing aerobic respiration (and from buffering of lactic acid by bicarbonate, which releases additional CO_2 non-metabolically), while relatively little extra O_2 is being consumed because most ATP is coming from anaerobic glycolysis (lactate fermentation), which uses no O_2 at all. The measured "RQ" in this context partly reflects non-respiratory CO_2 release rather than pure aerobic substrate oxidation.

Bài tập luyện tập

Explain why $FADH_2$ yields fewer ATP than NADH when both donate electrons to the electron transport chain.

Lời giải chi tiết

$FADH_2$ donates its electrons to the chain at a later point (a lower energy/redox potential entry point, associated with Complex II) than NADH does (which enters at Complex I). Because $FADH_2$'s electrons bypass the first proton-pumping complex, fewer protons are pumped into the intermembrane space per $FADH_2$ than per NADH, so less of a gradient is built and correspondingly less ATP is synthesised — approximately 1.5 ATP per $FADH_2$ versus approximately 2.5 ATP per NADH.

Bài tập luyện tập

A tissue culture is respiring using the malate–aspartate shuttle to import cytoplasmic NADH into the mitochondrion, versus another tissue using the glycerol phosphate shuttle. Explain why the second tissue produces a lower overall ATP yield from the same glucose.

Lời giải chi tiết

The malate–aspartate shuttle delivers electrons from cytoplasmic NADH into the matrix in a form that still enters the chain at Complex I (as NADH), yielding the full ≈2.5 ATP per pair of electrons. The glycerol phosphate shuttle instead delivers these electrons to the chain via FAD (entering at Complex II, bypassing Complex I), yielding only ≈1.5 ATP per pair of electrons — a smaller "toll" is paid to get the electrons across the membrane using this route. Tissues using the glycerol phosphate shuttle (e.g., some muscle/brain cells) therefore have a slightly lower overall ATP yield per glucose (closer to ≈30) than tissues using the malate–aspartate shuttle (closer to ≈32).

Bài tập luyện tập

A student claims: "Since glycolysis needs no oxygen, it must be an anaerobic process, and therefore it cannot be part of aerobic respiration." Evaluate this claim.

Lời giải chi tiết

The claim is **incorrect**. Glycolysis does not directly require oxygen, but it is a shared, universal first stage of *both* aerobic and anaerobic respiration — the distinction between "aerobic" and "anaerobic" respiration lies in what happens *after* glycolysis (whether pyruvate proceeds into the oxygen-requiring link reaction/Krebs cycle/oxidative phosphorylation, or is instead reduced anaerobically to lactate/ethanol to regenerate NAD^+). Glycolysis itself is common to both pathways.

Bài tập luyện tập

Calculate the RQ for an organism that consumes 1200 cm^3 of O_2 and produces 840 cm^3 of CO_2 in one hour, and use it to estimate the approximate percentage contribution of lipid versus carbohydrate to its respiratory substrate mixture (assume only these two substrates are used, $RQ_{carb} = 1.0$, $RQ_{lipid} = 0.7$).

Lời giải chi tiết

$$RQ = \frac{840}{1200} = 0.70$$

An RQ of exactly 0.70 matches pure lipid respiration ($RQ_{lipid} \approx 0.7$) — implying the organism is respiring almost entirely **lipid** at this time, with negligible carbohydrate contribution (since 0.70 is at the lipid end of the 0.7–1.0 range, not intermediate).

Bài tập luyện tập

Outline the sequence of stages an organic molecule of glucose passes through, from initial entry into glycolysis to being fully oxidised to CO_2 and H_2O, naming the location of each stage.

Lời giải chi tiết

(1) **Glycolysis** (cytoplasm): glucose (6C) $\rightarrow$ 2 pyruvate (3C), net 2 ATP $+$ 2 reduced NAD. (2) **Link reaction** (mitochondrial matrix, $\times 2$): pyruvate $\rightarrow$ acetyl CoA (2C) $+ CO_2$, $+$ reduced NAD. (3) **Krebs cycle** (mitochondrial matrix, 2 turns): acetyl CoA combines with oxaloacetate, releasing CO_2 and generating reduced NAD, reduced FAD, and ATP each turn, regenerating oxaloacetate. (4) **Oxidative phosphorylation** (inner mitochondrial membrane/cristae): reduced NAD/FAD deliver electrons to the electron transport chain; chemiosmosis (proton gradient $+$ ATP synthase) generates the majority of ATP; O_2 accepts electrons at the end of the chain, forming H_2O.

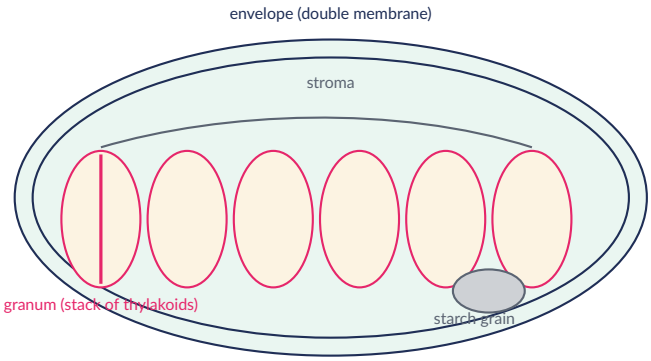
Photosynthesis

A2 Level

Mục tiêu Unit: Cấu tạo lục lạp và mối liên hệ với chức năng; sắc tố quang hợp và phổ hấp thụ/phổ tác dụng; phản ứng sáng (quang phân ly nước, chuỗi truyền electron, hoá thẩm, photphoryl hoá quang hợp theo chu trình và không theo chu trình); chu trình Calvin (cố định CO_2 nhờ RuBisCO, tái tạo RuBP); các yếu tố giới hạn quang hợp (ánh sáng, CO_2, nhiệt độ); thực hành đo tốc độ quang hợp (định luật nghịch đảo bình phương, phản ứng Hill với DCPIP); khái quát con đường C4.

10.1 Chloroplast structure recap

The chloroplast is the organelle in which photosynthesis takes place, and its internal architecture directly reflects the two stages of the process.



Chloroplast structure: a double outer **envelope**; internal membranes folded into flattened sacs (**thylakoids**) stacked into **grana** and interconnected by lamellae — the site of the light-dependent reactions, with photosystems and ATP synthase embedded in the thylakoid membrane; the fluid **stroma** surrounding the grana — the site of the light-independent reactions (Calvin cycle), containing the enzymes of the cycle, starch grains, and the chloroplast's own circular DNA and 70S ribosomes.

Structure–function links: the large surface area of stacked thylakoid membranes packs in as many light-harvesting pigment molecules, photosystems, electron carriers, and ATP synthase molecules as possible per unit volume, maximising light capture and ATP/reduced NADP production. The fluid stroma provides an aqueous environment with all the enzymes (including RuBisCO) needed for CO_2 fixation, positioned immediately adjacent to the thylakoids so that ATP and reduced NADP (produced there) reach the stroma with minimal diffusion distance. Chloroplasts contain their own circular DNA and 70S ribosomes (like mitochondria and bacteria), consistent with their evolutionary origin as endosymbiotic cyanobacteria-like prokaryotes (endosymbiotic theory).

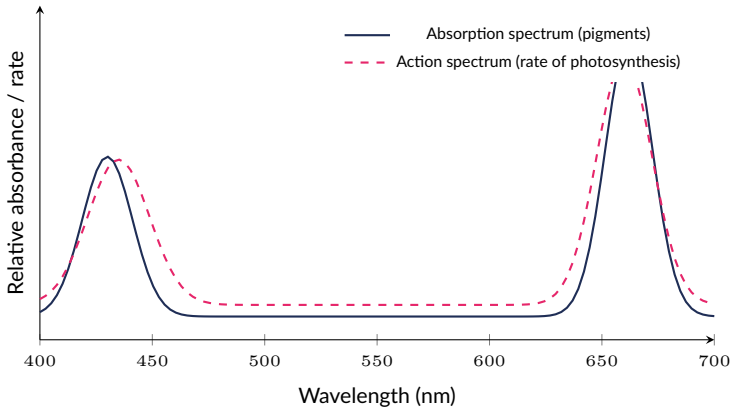
VN GIẢI THÍCH TIẾNG VIỆT

Lục lạp có **màng bao kép**; bên trong là hệ thống túi dẹt **thylakoid** xếp chồng thành **grana** — nơi

diễn ra **phản ứng sáng** (chứa hệ quang hoá, chuỗi truyền electron, ATP synthase); bao quanh grana là **stroma** dạng dịch lỏng — nơi diễn ra **phản ứng tối** (chu trình Calvin), chứa enzyme RuBisCO, hạt tinh bột dự trữ, và DNA vòng cùng ribosome 70S riêng của lục lạp (bằng chứng cho thuyết nội cộng sinh — lục lạp có nguồn gốc từ vi khuẩn lam cổ đại).

10.2 Photosynthetic pigments and light absorption

Photosynthetic pigments are light-absorbing molecules embedded in the thylakoid membrane. **Chlorophyll a** is the primary pigment directly involved in the reaction centres of both photosystems; **chlorophyll b** and **carotenoids** are accessory ("antenna") pigments that absorb light of wavelengths chlorophyll a absorbs poorly and pass the energy on to chlorophyll a by resonance energy transfer, broadening the range of usable wavelengths.



Absorption spectrum (how much light of each wavelength the extracted pigments absorb) closely matches the **action spectrum** (rate of photosynthesis at each wavelength) — both peak in the blue (≈430–450 nm) and red (≈660 nm) regions, with a trough in the green (≈500–560 nm), because chlorophyll reflects/transmits green light rather than absorbing it (which is why leaves appear green). The close match is strong evidence that these pigments are directly responsible for driving photosynthesis.

Absorption spectrum vs. action spectrum

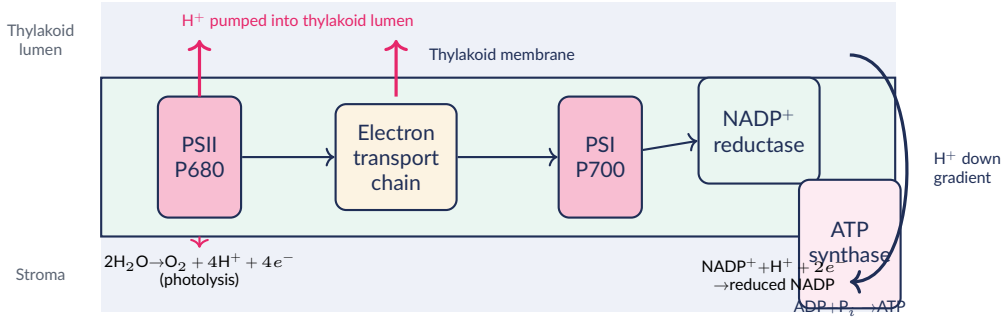
The **absorption spectrum** is measured directly from extracted pigments (e.g., using a spectrophotometer or chromatography), showing how much light of each wavelength is absorbed. The **action spectrum** is measured from a whole photosynthesising organism/tissue, showing the *rate of photosynthesis* produced by light of each wavelength (e.g., using rate of O_2 production). Because the two curves closely coincide, this is strong indirect evidence that the wavelengths absorbed by chlorophyll and carotenoids are the ones actually driving the light-dependent reactions — light of wavelengths poorly absorbed (green) produces a correspondingly low photosynthetic rate.

VN **GIẢI THÍCH TIẾNG VIỆT**

Phổ hấp thụ (absorption spectrum) đo trực tiếp trên sắc tố tách chiết, cho biết mức hấp thụ ánh sáng ở từng bước sóng; **phổ tác dụng** (action spectrum) đo tốc độ quang hợp thực tế của cây/mô ở từng bước sóng ánh sáng. Hai đường cong này **trùng khớp gần như hoàn toàn** — đỉnh ở vùng xanh dương và đỏ, đáy ở vùng xanh lục — là bằng chứng mạnh mẽ cho thấy diệp lục và carotenoid chính là các sắc tố thực sự thúc đẩy quang hợp (chứ không phải trùng hợp ngẫu nhiên).

10.3 Light-dependent reactions

The light-dependent reactions occur in the thylakoid membrane and convert light energy into the chemical energy of ATP and reduced NADP, while splitting water and releasing oxygen.



Light-dependent reactions (non-cyclic pathway). Light excites electrons at **PSII**; **photolysis** of water replaces these electrons and releases O_2 as a by-product. Electrons pass along an electron transport chain, pumping H^+ into the thylakoid lumen (chemiosmosis); H^+ flows back through **ATP synthase**, producing ATP (**photophosphorylation**). Electrons are re-energised by light at **PSI** and used (via $NADP^+$ reductase) to reduce $NADP^+$ to reduced NADP.

Photoactivation, photolysis, and the light-dependent pathway

Each **photosystem** is a cluster of chlorophyll and accessory pigment molecules (a light-harvesting antenna) surrounding a special pair of reaction-centre chlorophyll a molecules. Light energy absorbed anywhere in the antenna is funnelled to the reaction centre, where it excites an electron to a higher energy level (**photoactivation** / photoionisation), which is then captured by an electron acceptor.

At **photosystem II (PSII)**, the electrons lost from the reaction centre are replaced by **photolysis** of water:

$$2H_2O \rightarrow 4H^+ + 4e^- + O_2$$

This is the source of *all* the oxygen released by photosynthesis. The excited electrons pass along an **electron transport chain** to **photosystem I (PSI)**, releasing energy that pumps H^+ from the stroma into the thylakoid lumen, building a proton gradient across the thylakoid membrane. This drives **photophosphorylation**: H^+ flows back through ATP synthase (embedded in the thylakoid membrane), synthesising ATP — the same chemiosmotic principle as oxidative phosphorylation in mitochondria. At PSI, electrons are re-excited by further light absorption and are finally used (via the enzyme $NADP^+$ reductase) to reduce $NADP^+$ to **reduced NADP**, using electrons and H^+ from the stroma.

Cyclic photophosphorylation: in an alternative, supplementary pathway, electrons leaving the excited PSI reaction centre are passed back through part of the electron transport chain and returned to PSI itself, rather than reducing $NADP^+$. This still pumps H^+ and generates **ATP only** — no reduced NADP and no O_2 are produced (PSII and photolysis are not involved at all). Cyclic photophosphorylation supplements the ATP supply when the Calvin cycle needs relatively more ATP than reduced NADP.

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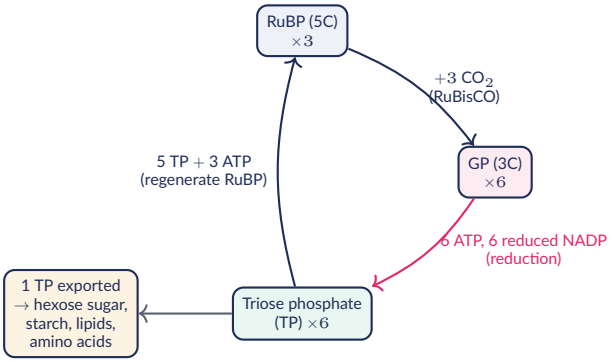
Ánh sáng kích thích electron tại **hệ quang hoá II (PSII)**; electron mất đi được bù lại nhờ **quang phân ly nước** ($2H_2O \rightarrow 4H^+ + 4e^- + O_2$) — đây chính là nguồn gốc của toàn bộ khí O_2 do quang hợp thải ra. Electron di chuyển qua chuỗi truyền electron đến **hệ quang hoá I (PSI)**, bơm H^+ vào xoang thylakoid, tạo gradient để tổng hợp ATP (**photphoryl hoá quang hợp**, cùng cơ chế hoá thẩm như ở ti thể). Tại PSI, electron được ánh sáng kích thích lần nữa và cuối cùng khử

NADP$^+$ thành **NADPH**. Ngoài ra còn có **photphoryl hoá vòng**: electron từ PSI quay vòng trở lại PSI (không qua PSII, không quang phân ly nước), chỉ tạo ATP mà không tạo NADPH hay O_2 — bổ sung ATP khi chu trình Calvin cần nhiều ATP hơn NADPH.

10.4 The Calvin cycle (light-independent reactions)

The Calvin cycle takes place in the stroma and uses the ATP and reduced NADP generated by the light-dependent reactions to fix and reduce carbon dioxide into organic molecules.



The Calvin cycle, scaled to 3 turns (3 CO_2 fixed). **RuBisCO** catalyses fixation of CO_2 onto **RuBP** (5C), forming an unstable 6C intermediate that immediately splits into two molecules of **GP** (glycerate 3-phosphate, 3C). GP is reduced (using ATP and reduced NADP) to **TP** (triose phosphate); most TP is recycled (using further ATP) to regenerate RuBP, while a smaller fraction is drawn off to build hexose sugars, starch, lipids, and amino acids.

Calvin cycle — the three phases

1. Carbon fixation: CO_2 combines with **ribulose bisphosphate (RuBP, 5C)**, catalysed by the enzyme **RuBisCO** (ribulose bisphosphate carboxylase/oxygenase — thought to be the most abundant enzyme on Earth), forming an unstable 6-carbon intermediate that immediately splits into **two molecules of glycerate 3-phosphate (GP, 3C)**.
2. Reduction: each GP is phosphorylated (using ATP) and then reduced (using reduced NADP, which donates electrons/hydrogen) to form **triose phosphate (TP, 3C)**, regenerating NADP$^+$ and ADP $+P_i$ to be recycled back to the light-dependent reactions.
3. Regeneration: of every 6 TP produced, 5 are used (with further ATP) to regenerate 3 molecules of RuBP, keeping the cycle running; the remaining **1 TP** is exported from the cycle and used to synthesise glucose and other organic molecules — hexose sugars, sucrose, starch, cellulose, lipids, and (with added nitrogen) amino acids.

Scaled up to **6 CO_2** fixed (6 turns of the cycle), the Calvin cycle produces **2 TP** net (enough to combine into 1 hexose sugar, e.g., glucose), consuming a total of **18 ATP** and **12 reduced NADP**. The overall summary equation:

$$6CO_2 + 12\,\text{reduced NADP} + 18\,\text{ATP} \rightarrow C_6H_{12}O_6 + 12\text{NADP}^+ + 18\text{ADP} + 18P_i + 6H_2O$$

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Chu trình Calvin diễn ra ở stroma, gồm 3 pha: **cố định carbon** (CO_2 kết hợp với RuBP nhờ enzyme **RuBisCO**, tạo hợp chất 6C không bền, lập tức tách thành 2 phân tử GP 3C); **khử** (GP được phosphoryl hoá bằng ATP rồi khử bằng NADPH thành **triose phosphate TP**); **tái tạo** (5/6 TP dùng thêm ATP để tái tạo RuBP, duy trì chu trình; 1/6 TP được xuất ra để tổng hợp glucose, tinh bột, lipid, amino acid). Khi cố định đủ 6 CO_2 (6 vòng), chu trình tạo được 1 phân tử đường

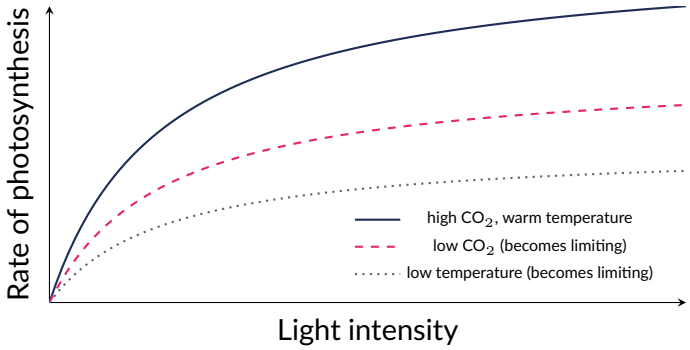
6C (hexose), tiêu tốn tổng cộng 18 ATP và 12 NADPH.

Feature	Light-dependent reactions	Light-independent reactions (Calvin cycle)
Location	Thylakoid membrane	Stroma
Requires light directly?	Yes	No (but depends on ATP/reduced NADP from light-dependent reactions)
Key inputs	Light, H_2O, ADP $+P_i$, $NADP^+$	CO_2, ATP, reduced NADP, RuBP
Key outputs	ATP, reduced NADP, O_2	Triose phosphate (TP)/hexose sugar, ADP $+P_i$, $NADP^+$
Key enzyme/protein	Photosystems I & II, ATP synthase	RuBisCO

Summary: light-dependent vs. light-independent reactions.

(!) Lỗi thường gặp: "Phản ứng tối" (dark reactions) không có nghĩa là chỉ xảy ra vào ban đêm — chu trình Calvin có thể diễn ra bất cứ lúc nào miễn là có đủ ATP và NADPH (thường do phản ứng sáng cung cấp liên tục ban ngày); tên gọi "light-independent" chỉ có nghĩa là bản thân các phản ứng này không trực tiếp cần ánh sáng, chứ hoàn toàn phụ thuộc gián tiếp vào sản phẩm của phản ứng sáng.

10.5 Limiting factors



At low light intensity, all three curves rise together — light is the limiting factor. Each curve plateaus at a different height: the plateau is set by whichever *other* factor (CO_2 concentration or temperature) is in shortest supply for that condition. Raising light further, alone, cannot raise the rate above a plateau caused by a different limiting factor.

Blackman's principle of limiting factors

When a process depends on several factors, the rate at any moment is limited by whichever factor is in **shortest supply** relative to the others — increasing that one factor raises the rate (until a new factor becomes limiting), while increasing any other factor has no effect. Graphically, this is seen as a rate curve that rises steeply then plateaus: on the rising part, the plotted factor (e.g., light intensity) is limiting; on the plateau, some *other* factor (not shown on the x-axis) has become limiting.

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Định luật yếu tố giới hạn (Blackman): khi một quá trình phụ thuộc vào nhiều yếu tố, tốc độ tại một thời điểm bị giới hạn bởi yếu tố đang ở mức **thấp nhất tương đối** — chỉ tăng yếu tố đó

mới làm tăng tốc độ; tăng các yếu tố khác không có tác dụng cho đến khi yếu tố giới hạn thay đổi. Trên đồ thị, phần đường cong dốc lên cho thấy yếu tố trên trục hoành đang giới hạn; phần nằm ngang (plateau) cho thấy một yếu tố *khác* (không phải trục hoành) mới là yếu tố giới hạn lúc đó.

10.6 Investigating rate of photosynthesis

10.6.1 Counting bubbles and the inverse square law

A common practical uses aquatic pondweed (e.g., *Elodea* or *Cabomba*): a cut stem releases bubbles of gas (mostly O_2) from its cut end, and the number of bubbles released per unit time is used as an estimate of the rate of photosynthesis. Varying the **distance** of a lamp from the pondweed varies the light intensity reaching it. Because light intensity from a point source obeys the **inverse square law**:

$$I \propto \frac{1}{d^2} \qquad \text{so} \qquad \frac{I_2}{I_1} = \left(\frac{d_1}{d_2}\right)^2$$

where I is light intensity and d is distance from the light source. Doubling the distance reduces intensity to one quarter; tripling the distance reduces it to one ninth.

10.6.2 The Hill reaction and DCPIP

Robert Hill showed that isolated chloroplasts (or thylakoid membrane fragments), when illuminated in the presence of an artificial electron acceptor, release oxygen *without* any CO_2 being fixed — demonstrating that photolysis/O_2 release and the light-dependent electron transport chain are biochemically independent of the Calvin cycle. In the classic version of this experiment, the blue dye **DCPIP** (2,6-dichlorophenolindophenol) is used as an artificial electron acceptor in place of $NADP^+$: DCPIP is blue when **oxidised** and turns **colourless** when **reduced** (having accepted electrons from the electron transport chain instead of $NADP^+$). Illuminated chloroplasts with DCPIP therefore change from blue to colourless, and the *rate* of this colour change (measured, e.g., with a colorimeter) can be used as a proxy for the rate of the light-dependent reactions.

VN **GIẢI THÍCH TIẾNG VIỆT**

Thí nghiệm đếm bọt khí ở rong đuôi chó (*Elodea*/*Cabomba*) dùng số bọt khí/thời gian để ước lượng tốc độ quang hợp; khi thay đổi **khoảng cách** đèn, cường độ ánh sáng thay đổi theo **định luật nghịch đảo bình phương**: $I \propto 1/d^2$. **Phản ứng Hill**: lục lạp tách chiết, khi chiếu sáng cùng chất nhận electron nhân tạo (như **DCPIP**), vẫn giải phóng O_2 dù không có CO_2 để cố định — chứng minh phản ứng sáng (quang phân ly nước, chuỗi truyền electron) độc lập về mặt sinh hoá với chu trình Calvin. DCPIP có màu **xanh khi bị oxy hoá**, chuyển sang **không màu khi bị khử** — tốc độ mất màu phản ánh tốc độ phản ứng sáng.

10.7 The C4 pathway (concept)

Most plants (**C3 plants**) fix CO_2 directly via RuBisCO, whose active site can also bind O_2 instead of CO_2 (an oxygenase reaction called **photorespiration**), wasting energy and fixed carbon — a problem that worsens in hot, bright, dry conditions when leaf stomata partly close (conserving water) and internal CO_2 concentration falls while O_2 rises.

The C4 CO_2-concentrating mechanism

Some plants adapted to hot, high-light environments (e.g., **maize**, sugarcane) evolved a "CO_2-pump": in mesophyll cells, the enzyme **PEP carboxylase** (which has a much higher affinity

for CO_2 than RuBisCO and does not bind O_2) fixes CO_2 onto a 3-carbon compound (PEP) to form a **4-carbon** compound (hence "C4"). This 4C compound is transported into specialised **bundle sheath cells**, where it is broken down to release CO_2 at high local concentration around RuBisCO — effectively concentrating CO_2 and out-competing O_2 for RuBisCO's active site, minimising photorespiration and allowing efficient photosynthesis even with stomata partly closed in hot, bright conditions.

VN **GIẢI THÍCH TIẾNG VIỆT**

Ở thực vật **C3**, RuBisCO đôi khi gắn nhầm với O_2 thay vì CO_2 (gọi là **quang hô hấp**), gây lãng phí năng lượng — vấn đề này nghiêm trọng hơn khi trời nóng, sáng, khô (khí khổng đóng bớt để giữ nước, làm CO_2 nội bào giảm, O_2 tăng). Thực vật **C4** (như ngô) tiến hoá một "bơm CO_2": enzyme **PEP carboxylase** ở tế bào thịt lá có ái lực với CO_2 cao hơn nhiều và không gắn với O_2, cố định CO_2 thành hợp chất 4C, chuyển vào tế bào bao bó mạch để giải phóng CO_2 nồng độ cao quanh RuBisCO — giúp giảm thiểu quang hô hấp và duy trì quang hợp hiệu quả trong điều kiện nóng, sáng.

10.8 Worked examples

Inverse square law — predicting bubble rate at a new distance

A lamp placed 20 cm from pondweed produces a bubble rate of 32 bubbles per minute. Assuming light intensity is the limiting factor and bubble rate is directly proportional to light intensity, predict the bubble rate if the lamp is moved to 40 cm.

$$\frac{I_{40}}{I_{20}} = \left(\frac{20}{40}\right)^2 = \left(\frac{1}{2}\right)^2 = \frac{1}{4}$$

Predicted rate at 40 cm: $32 \times \frac{1}{4} =$ **8** bubbles per minute.

Inverse square law — testing whether light is truly limiting

At 10 cm from the lamp, a bubble rate of 54 min^{-1} is recorded. At 30 cm, the rate is 9 min^{-1}. Determine whether this is consistent with light being the sole limiting factor obeying the inverse square law.

Predicted ratio: $\left(\frac{10}{30}\right)^2 = \frac{1}{9}$, so predicted rate at 30 cm should be $54 \times \frac{1}{9} = 6$ min^{-1}. The observed rate (9 min^{-1}) is *higher* than predicted, suggesting light intensity alone does not fully explain the data — for example, the closer lamp (10 cm) may also have warmed the water noticeably (heat from the bulb), artificially raising the rate at short distance beyond what light intensity alone would produce, or another factor (CO_2) may already be co-limiting at short distances.

Interpreting a limiting factors graph

In an experiment, increasing light intensity raises the rate of photosynthesis of a plant up to a plateau at 20 arbitrary units; the plateau does not increase further even at very high light intensity, but rises to 30 units when atmospheric CO_2 is doubled (at the same high light intensity). Identify the limiting factor(s) in each part of the original experiment.

On the rising part of the curve (before the plateau), **light intensity** is limiting. At the plateau (with normal CO_2), **CO_2 concentration** has become the limiting factor — this is confirmed because increasing CO_2 (while light remains high) raises the rate further, showing light was no longer the constraint at that point.

Hill reaction / DCPIP colour-change interpretation

Isolated chloroplasts are illuminated in a test tube containing DCPIP. Over 10 minutes, the mixture changes from deep blue to colourless. A second, identical tube kept in the dark shows no colour change over the same period. Explain these observations.

In the light, the chloroplasts' light-dependent reactions proceed: PSII is excited, water is photolysed, and electrons pass along the electron transport chain — but here DCPIP (rather than $NADP^+$) acts as the terminal electron acceptor. As DCPIP accepts electrons, it is **reduced** and loses its blue colour, becoming colourless; the rate of colour loss is therefore a direct proxy for the rate of the light-dependent electron transport chain. In the dark tube, no photoactivation of chlorophyll can occur, so no electrons are released to reduce DCPIP, and it remains blue (oxidised) — confirming that this colour change specifically requires light (and demonstrating that O_2/electron release occurs independently of the Calvin cycle, since no CO_2 fixation is involved here at all).

Bubble counting: converting bubbles to a volume-based rate

Bubbles released by illuminated pondweed are collected and counted: 60 bubbles are produced in 3 minutes. Each bubble has an average diameter of 3.0 mm (radius 1.5 mm $= 0.15$ cm). Calculate the rate of oxygen production in $\text{cm}^3\ \text{min}^{-1}$.

Volume of one bubble (sphere): $V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(0.15)^3 = \frac{4}{3}\pi(0.003375) \approx 0.01414\ \text{cm}^3$. Total volume from 60 bubbles: $60 \times 0.01414 \approx 0.848\ \text{cm}^3$.

$$\text{Rate} = \frac{0.848\ \text{cm}^3}{3\ \text{min}} \approx 0.283\ \text{cm}^3\ \text{min}^{-1}$$

Tracing a carbon atom through the Calvin cycle

A molecule of $^{14}CO_2$ (radioactively labelled) is supplied to an illuminated plant. Trace the path of this single labelled carbon atom through one turn of the Calvin cycle, up to the point where it might first appear in a hexose sugar.

The labelled CO_2 combines with RuBP (5C), catalysed by RuBisCO, forming an unstable 6C intermediate that immediately splits into **two GP molecules** (3C each) — the labelled carbon is now present in one of these two GP molecules. That GP is phosphorylated and reduced (using ATP and reduced NADP) to **triose phosphate (TP)**, so the label is now in a TP molecule. From here, the labelled TP molecule may follow one of two routes: (a) it may be one of the 5-in-6 TP molecules used (with further ATP) to regenerate RuBP, keeping the label cycling within the pathway for now; or (b) it may be the 1-in-6 TP molecule exported from the cycle, where two exported TP molecules combine to form one hexose sugar (e.g., glucose) — at which point the originally labelled carbon atom appears in the sugar product.

Calvin cycle ATP/NADPH bookkeeping

Calculate the total ATP and reduced NADP required to fix 18 molecules of CO_2 via the Calvin cycle, and state how many hexose sugar molecules this could ultimately produce.

Fixing 6 CO_2 requires 18 ATP and 12 reduced NADP and yields (net) enough TP for 1 hexose sugar. Scaling to 18 CO_2 (3×6):

$$\text{ATP required} = 3 \times 18 = 54 \text{ ATP}, \qquad \text{reduced NADP required} = 3 \times 12 = 36$$

This would yield enough net triose phosphate to produce **3** hexose sugar molecules.

Interpreting the absorption/action spectrum graph

Using the absorption/action spectrum graph in this unit, predict and explain the relative rate of photosynthesis of a plant illuminated with (a) pure green light (≈ 550 nm) and (b) pure red light (≈ 660 nm), assuming equal light intensity (equal number of photons) in both cases.

(a) Green light (≈ 550 nm) falls in the **trough** of both spectra — chlorophyll and carotenoids absorb very little green light (most is reflected/transmitted, which is why leaves appear green), so relatively little of this light energy is captured, and the rate of photosynthesis is **low**. (b) Red light (≈ 660 nm) falls near a **peak** of both spectra — it is strongly absorbed by chlorophyll a, so a much **higher** rate of photosynthesis is expected at equal photon intensity.

C3 vs. C4 performance under hot, bright conditions

On a hot, sunny day, a maize plant (C4) maintains a much higher net photosynthetic rate than a nearby C3 crop of the same leaf area, even though both experience the same light intensity, temperature, and partially closed stomata. Explain this difference.

With stomata partly closed to conserve water in hot conditions, internal CO_2 concentration falls and O_2 concentration (from ongoing photosynthesis/photorespiration) rises inside both types of leaf. In the C3 crop, RuBisCO increasingly binds O_2 instead of CO_2 (photorespiration), wasting energy and fixed carbon and lowering net photosynthetic rate. In maize (C4), **PEP carboxylase** in the mesophyll cells has a very high affinity for the remaining CO_2 and does not bind O_2 at all; it continues fixing CO_2 efficiently and delivers it, concentrated, to bundle sheath cells around RuBisCO — largely avoiding photorespiration and sustaining a much higher net rate of photosynthesis under these hot, bright, water-limited conditions.

10.9 Practice bank

Bài tập luyện tập

State the location within the chloroplast of (a) the light-dependent reactions and (b) the Calvin cycle.

Lời giải chi tiết

(a) The light-dependent reactions occur in the **thylakoid membrane** (where photosystems, the electron transport chain, and ATP synthase are embedded). (b) The Calvin cycle occurs in the **stroma** (the fluid matrix surrounding the thylakoids, containing RuBisCO and the other Calvin cycle enzymes).

Bài tập luyện tập

Which structural feature of chloroplasts most directly maximises light capture, and why?

(A) The double outer envelope

(B) Thylakoids stacked into grana, greatly increasing surface area available for pigment/photosystem packing

(C) The presence of starch grains

(D) The chloroplast's own circular DNA

Lời giải chi tiết

Stacking thylakoids into grana greatly increases the membrane surface area within a small volume, allowing many more photosystems and pigment molecules to be packed in, maximising light capture. **(B)**.

Bài tập luyện tập

Distinguish between an absorption spectrum and an action spectrum, and explain why their similarity is significant.

Lời giải chi tiết

An **absorption spectrum** shows how much light of each wavelength is absorbed by extracted pigments; an **action spectrum** shows the rate of photosynthesis produced by each wavelength in a living plant/tissue. Their close similarity (both peaking in blue/red, both showing a trough in green) is strong evidence that the pigments responsible for the absorption spectrum are the ones actually driving photosynthesis — wavelengths well absorbed correspond to wavelengths that produce a high photosynthetic rate.

Bài tập luyện tập

Why do carotenoids and chlorophyll b, despite not being directly located at reaction centres, still increase overall photosynthetic efficiency?

(A) They act as accessory (antenna) pigments, absorbing wavelengths that chlorophyll a absorbs poorly and passing the energy to chlorophyll a, broadening the usable light spectrum

(B) They directly split water at PSII

(C) They replace chlorophyll a entirely in older leaves

(D) They function only as structural proteins

Lời giải chi tiết

Accessory pigments absorb additional wavelengths (e.g., carotenoids absorb strongly in the blue region) that chlorophyll a itself absorbs less efficiently, then transfer that captured energy to chlorophyll a at the reaction centre — broadening the overall range of light wavelengths the plant can use. **(A)**.

Bài tập luyện tập

Name the process at photosystem II that replaces electrons lost from the reaction centre, and state its two other products.

Lời giải chi tiết

The process is **photolysis** of water: $2H_2O \rightarrow 4H^+ + 4e^- + O_2$. Besides replacing the lost electrons, this releases **protons (H^+)** (contributing to the proton gradient) and **oxygen gas (O_2)**, the source of all photosynthetically-produced O_2.

Bài tập luyện tập

Describe how a proton gradient across the thylakoid membrane leads to ATP synthesis, and name this overall process.

Lời giải chi tiết

As excited electrons pass along the electron transport chain from PSII to PSI, energy released pumps H^+ from the stroma into the thylakoid lumen, building a steep proton gradient across the thylakoid membrane. H^+ flows back into the stroma only through **ATP synthase**, and this flow drives ATP synthesis from ADP $+P_i$. This whole mechanism — an electron transport chain generating a gradient used by ATP synthase — is **chemiosmosis**, here specifically called **photophosphorylation** since it is driven by light-excited electrons.

Bài tập luyện tập

What is the fate of electrons that reach photosystem I in the non-cyclic pathway?

(A) They are released as heat

(B) They are re-excited by light and ultimately used to reduce $NADP^+$ to reduced NADP

(C) They immediately split water

(D) They are directly used to fix CO_2

Lời giải chi tiết

At PSI, electrons are re-energised by further light absorption and passed (via $NADP^+$ reductase) to reduce $NADP^+$ to reduced NADP, which is then used in the Calvin cycle. **(B)**.

Bài tập luyện tập

Describe cyclic photophosphorylation and explain why it produces no reduced NADP or oxygen.

Lời giải chi tiết

In cyclic photophosphorylation, electrons excited at PSI are passed back through part of the electron transport chain and return to PSI itself (rather than reducing $NADP^+$), still pumping H^+ and generating ATP as they do so. Because PSII and photolysis of water are not involved at all in this pathway, no O_2 is released; and because the electrons cycle back to PSI rather than being passed on to $NADP^+$ reductase, no reduced NADP is produced — only ATP.

Bài tập luyện tập

Name the enzyme that catalyses carbon fixation in the Calvin cycle, and state precisely what it combines CO_2 with.

Lời giải chi tiết

The enzyme is **RuBisCO** (ribulose bisphosphate carboxylase/oxygenase). It combines CO_2 with **ribulose bisphosphate (RuBP, 5C)**, forming an unstable 6-carbon intermediate that immediately splits into two molecules of glycerate 3-phosphate (GP, 3C).

Bài tập luyện tập

Per turn of the Calvin cycle (one CO_2 fixed), how many GP and TP molecules are involved, and how many ATP/reduced NADP are used to convert GP to TP?

(A) 1 GP, 1 TP, 1 ATP

(B) 2 GP, 2 TP, 2 ATP and 2 reduced NADP

(C) 3 GP, 3 TP, 3 ATP only

(D) 2 GP, 1 TP, 1 reduced NADP

Lời giải chi tiết

Fixing 1 CO_2 onto RuBP produces **2 GP** molecules (from splitting the unstable 6C intermediate); these 2 GP are reduced to **2 TP**, requiring **2 ATP** (for phosphorylation) and **2 reduced NADP** (for reduction). **(B)**.

Bài tập luyện tập

Of every 6 triose phosphate (TP) molecules produced in the Calvin cycle, how many are used to regenerate RuBP, and how many are exported to build other organic molecules?

Lời giải chi tiết

5 of the 6 TP molecules are used (with further ATP) to regenerate 3 molecules of RuBP, keeping the cycle running. The remaining **1 TP** is exported from the cycle to build hexose sugars, starch, lipids, and (with added nitrogen) amino acids.

Bài tập luyện tập

Calculate the total ATP and reduced NADP consumed by the Calvin cycle to fix 12 molecules of CO_2, and state how many hexose sugar molecules this could produce.

Lời giải chi tiết

Fixing 6 CO_2 requires 18 ATP and 12 reduced NADP, yielding 1 hexose. Scaling to 12 CO_2 (2×6): ATP $= 2 \times 18 =$ **36**; reduced NADP $= 2 \times 12 =$ **24**; hexose sugars produced $=$ **2**.

Bài tập luyện tập

If the light-dependent reactions are suddenly stopped (light switched off) but CO_2 is still available, explain what happens immediately to GP and RuBP concentrations.

(A) GP accumulates (no more ATP/reduced NADP to reduce it) and RuBP falls (still consumed to fix CO_2 but no longer regenerated)

(B) Both GP and RuBP immediately disappear

(C) RuBP accumulates and GP falls

(D) Neither changes, since the Calvin cycle is entirely independent of light

Lời giải chi tiết

Without light, ATP and reduced NADP supply stops, so GP cannot be reduced to TP — GP **accumulates**. Meanwhile RuBP is still being consumed (combined with CO_2 to form GP) but can no longer be regenerated (regeneration also needs ATP), so RuBP **falls**. **(A)**.

Bài tập luyện tập

If CO_2 supply is suddenly cut off but light remains available, explain what happens immediately to GP and RuBP concentrations.

Lời giải chi tiết

With light still available, ATP and reduced NADP continue to be produced normally. Without CO_2, RuBisCO can no longer fix carbon, so RuBP is no longer being consumed — RuBP **accumulates**. Meanwhile no new GP is being formed (since carbon fixation has stopped), while existing GP continues to be reduced to TP (regenerating more RuBP) — so GP **falls**.

Bài tập luyện tập

A greenhouse crop's photosynthesis rate plateaus at high light intensity even though CO_2 is supplied at atmospheric levels. Suggest and justify one change that would raise the plateau.

Lời giải chi tiết

Increase CO_2 concentration in the greenhouse (e.g., by artificial enrichment). If light is no longer limiting at the plateau, then CO_2 (or temperature) must be the limiting factor there; raising CO_2 supply would allow the light-independent reactions (RuBisCO activity) to proceed faster, raising the overall rate until a new factor becomes limiting.

Bài tập luyện tập

In an experiment, increasing temperature from $15\,^{\circ}$C to $25\,^{\circ}$C increases the rate of photosynthesis, but a further increase to $45\,^{\circ}$C sharply decreases it. Explain the decrease at $45\,^{\circ}$C.

(A) CO_2 suddenly becomes unavailable at high temperature

(B) Enzymes (e.g., RuBisCO) controlling the light-independent reactions begin to denature at high temperature, reducing their activity

(C) Light intensity decreases with higher temperature

(D) Chlorophyll turns green at high temperature

Lời giải chi tiết

Like all enzymes, RuBisCO and other photosynthetic enzymes have an optimum temperature; above it, bonds maintaining their tertiary structure break down (denaturation), sharply reducing the rate of the light-independent reactions and hence overall photosynthesis. **(B)**.

Bài tập luyện tập

A lamp is placed 15 cm from pondweed, producing a bubble rate of 45 min^{-1}. Predict the bubble rate if the lamp is moved to 45 cm, assuming light remains the limiting factor throughout.

Lời giải chi tiết

$$\frac{I_{45}}{I_{15}} = \left(\frac{15}{45}\right)^2 = \left(\frac{1}{3}\right)^2 = \frac{1}{9}$$

Predicted rate $= 45 \times \frac{1}{9} =$ **5** bubbles per minute.

Bài tập luyện tập

A lamp is moved from 8 cm to 24 cm from pondweed. If the bubble rate at 8 cm was 63 min^{-1}, predict the new rate at 24 cm.

Lời giải chi tiết

$$\frac{I_{24}}{I_{8}} = \left(\frac{8}{24}\right)^2 = \left(\frac{1}{3}\right)^2 = \frac{1}{9}$$

Predicted rate $= 63 \times \frac{1}{9} =$ **7** bubbles per minute.

Bài tập luyện tập

Explain one limitation of using bubble counting as a measure of the rate of photosynthesis.

Lời giải chi tiết

Bubbles vary in size, so counting the *number* of bubbles per minute does not necessarily reflect the true *volume* of gas released per minute (a valid concern unless bubble volume is also measured or standardised); additionally, gas released may not be pure O_2 (some may be dissolved gas released mechanically from cutting the stem, or the bubble stream may be irregular/intermittent), reducing accuracy compared to a proper gas-collection method.

Bài tập luyện tập

Describe the Hill reaction and explain its historical significance for understanding photosynthesis.

Lời giải chi tiết

Robert Hill illuminated isolated chloroplasts (or thylakoid fragments) in the presence of an artificial electron acceptor (e.g., DCPIP) and observed that O_2 was released even though no CO_2 was present to be fixed. This was historically significant because it demonstrated, for the first time, that the light-dependent reactions (photolysis of water and electron transport) are biochemically **independent** of the Calvin cycle/CO_2 fixation — showing that O_2 release does not require CO_2 at all, correcting the earlier assumption that O_2 came directly from CO_2 rather than from water.

Bài tập luyện tập

In a DCPIP experiment, which colour change indicates that the light-dependent reactions are occurring, and why?

(A) Colourless to blue, because DCPIP is being oxidised by CO_2

(B) Blue to colourless, because DCPIP is being reduced by electrons from the electron transport chain

(C) No colour change is expected in this experiment

(D) Blue to red, indicating pH change only

Lời giải chi tiết

DCPIP is blue when oxidised and turns colourless when reduced by electrons that would otherwise reduce $NADP^+$; a shift from blue to colourless indicates active electron transport driven by the light-dependent reactions. **(B)**.

Bài tập luyện tập

State two structural adaptations of a leaf that maximise light capture for photosynthesis, and relate each to its function.

Lời giải chi tiết

(1) Broad, thin lamina — maximises surface area exposed to light while keeping diffusion distances for CO_2/O_2 short. (2) A single layer of closely packed palisade mesophyll cells (rich in chloroplasts) near the upper leaf surface — positions the greatest density of chloroplasts where light intensity is highest, maximising light absorption before it is attenuated deeper into the leaf. (Accept also: transparent epidermis/cuticle allowing light through with minimal absorption; chloroplasts able to reorient within cells toward the light source.)

Bài tập luyện tập

Explain, using the concept of limiting factors, why increasing atmospheric CO_2 concentration alone would not necessarily increase crop yield in a poorly-lit greenhouse.

Lời giải chi tiết

If light intensity (not CO_2) is currently the limiting factor in a poorly-lit greenhouse, then the rate of photosynthesis is already constrained by the low light supply — increasing CO_2 concentration would have little or no effect on the rate, since a different factor is limiting. Only increasing the currently-limiting factor (in this case, light intensity, e.g., with supplementary lighting) would raise the rate, until some other factor (perhaps then CO_2, or temperature) became limiting instead.

Bài tập luyện tập

Outline why C4 plants such as maize typically outperform C3 plants in hot, high-light, and low-water environments.

Lời giải chi tiết

In hot, dry conditions, C3 plants must partly close their stomata to conserve water, which lowers internal CO_2 and raises internal O_2, increasing wasteful photorespiration by RuBisCO (which binds O_2 instead of CO_2). C4 plants avoid this using PEP carboxylase (in mesophyll cells), which has a very high affinity for CO_2 and does not bind O_2, fixing CO_2 into a 4-carbon compound even at low internal CO_2 concentrations; this compound is transported to bundle

sheath cells and broken down to release CO_2 at high local concentration around RuBisCO, largely eliminating photorespiration. This CO_2-concentrating mechanism lets C4 plants maintain efficient photosynthesis with stomata more closed, conserving water in hot, bright environments.

Bài tập luyện tập

Explain why RuBisCO's ability to bind O_2 as well as CO_2 can be considered an evolutionary "imperfection," and why C3 plants have not all evolved the C4 pathway.

Lời giải chi tiết

RuBisCO evolved in an ancient atmosphere with much higher CO_2 and lower O_2 than today, when its ability to also bind O_2 (photorespiration) had little practical cost; as atmospheric O_2 rose and CO_2 fell over evolutionary time, this became a genuine inefficiency. However, the C4 pathway requires additional enzymes (PEP carboxylase), specialised bundle sheath cell anatomy, and extra ATP (to regenerate PEP), representing a real metabolic cost; in cooler, well-watered, or shaded environments where stomata need not close and internal CO_2 stays relatively high, this extra cost is not repaid by a large enough reduction in photorespiration, so the simpler C3 pathway remains more efficient overall in those conditions.

Bài tập luyện tập

A student measures oxygen production from pondweed at five different light intensities and plots rate against intensity, obtaining a curve that rises linearly then plateaus. Describe how the student could determine experimentally whether CO_2 or temperature is the limiting factor at the plateau.

Lời giải chi tiết

Keeping light intensity fixed at the plateau level, the student could independently vary (a) CO_2 concentration (e.g., by adding sodium bicarbonate solution at increasing concentrations to the water) while keeping temperature constant, and separately (b) temperature (using a water bath) while keeping CO_2 constant. If increasing CO_2 raises the rate above the original plateau, CO_2 was the limiting factor; if increasing temperature (within a reasonable range) raises the rate instead, temperature was limiting. Each variable should be tested independently, with the other held constant, to isolate which factor is responsible.

Bài tập luyện tập

Bubbles are collected from illuminated pondweed: 90 bubbles in 5 minutes, average bubble diameter 2.4 mm (radius 1.2 mm $= 0.12$ cm). Calculate the rate of oxygen production in $\text{cm}^3\,\text{min}^{-1}$.

Lời giải chi tiết

Volume of one bubble: $V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(0.12)^3 = \frac{4}{3}\pi(0.001728) \approx 0.00724$ cm^3. Total volume: $90 \times 0.00724 \approx 0.652$ cm^3.

$$\text{Rate} = \frac{0.652\ \text{cm}^3}{5\ \text{min}} \approx 0.130\ \text{cm}^3\,\text{min}^{-1}$$

Bài tập luyện tập

A plant physiologist measures light intensity at I_0 at a reference distance $d_0 = 10$ cm from a lamp. At what distance would the light intensity fall to exactly one-sixteenth of I_0?

Lời giải chi tiết

$\frac{I}{I_0} = \left(\frac{d_0}{d}\right)^2 = \frac{1}{16} \Rightarrow \frac{d_0}{d} = \frac{1}{4} \Rightarrow d = 4d_0 = 4 \times 10 = \mathbf{40\ cm}$.

Bài tập luyện tập

Explain why chlorophyll appears green to the human eye, linking this directly to its absorption spectrum.

Lời giải chi tiết

Chlorophyll strongly absorbs light in the blue (≈ 430–450 nm) and red (≈ 660 nm) regions of the visible spectrum, but absorbs very little light in the green region (≈ 500–560 nm); this green light is instead reflected and transmitted rather than absorbed, and it is this reflected/transmitted green light that reaches the human eye — which is why chlorophyll-containing leaves appear green.

Bài tập luyện tập

Distinguish clearly between substrate-level events in the Calvin cycle (carbon fixation, reduction, regeneration) and the corresponding molecules involved at each step, using a fully labelled description (no diagram).

Lời giải chi tiết

Fixation: CO_2 + RuBP (5C) $\xrightarrow{\text{RuBisCO}}$ unstable 6C intermediate $\rightarrow$ 2 GP (3C). **Reduction:** GP + ATP (phosphorylation) then + reduced NADP (reduction) $\rightarrow$ TP (3C) + ADP + P_i + $NADP^+$. **Regeneration:** 5 of 6 TP + ATP $\rightarrow$ 3 RuBP regenerated; 1 of 6 TP exported to build hexose sugars/starch/lipids/amino acids.

Bài tập luyện tập

A researcher adds an inhibitor that specifically blocks ATP synthase in the thylakoid membrane, without affecting the electron transport chain carriers. Predict the immediate effects on (a) the size of the thylakoid proton gradient and (b) the rate of CO_2 fixation by the Calvin cycle.

Lời giải chi tiết

(a) The proton gradient across the thylakoid membrane **increases** initially — H^+ continues to be pumped into the thylakoid lumen by the electron transport chain (driven by light-excited electrons at PSII/PSI), but can no longer flow back out through ATP synthase (now blocked), so H^+ accumulates and the gradient steepens; eventually this steep "back-pressure" also slows electron flow along the chain itself. (b) The rate of CO_2 fixation by the Calvin cycle **falls**, because ATP synthesis (photophosphorylation) has stopped almost entirely; without a fresh supply of ATP (needed for both the reduction of GP to TP and the regeneration of RuBP), the

Calvin cycle cannot continue to run at its normal rate, even though reduced NADP production may continue for a short time via any electrons still reaching PSI.

Bài tập luyện tập

A student states: "Photosynthesis only needs light, water, and carbon dioxide; temperature makes no real difference once these three are supplied in excess." Evaluate this claim with reference to the limiting factors principle.

Lời giải chi tiết

The claim is **incorrect**. Even with light, water, and CO_2 in excess, the Calvin cycle depends on enzymes (notably RuBisCO) whose activity is temperature-sensitive: too low a temperature slows the rate of enzyme-catalysed reactions (reduced kinetic energy, fewer successful enzyme–substrate collisions), while too high a temperature causes progressive denaturation of these enzymes, both of which reduce the overall rate of photosynthesis regardless of how much light, water, or CO_2 is available. Temperature can therefore act as the limiting factor in its own right, independent of the other three variables, consistent with Blackman's principle that the rate is set by whichever factor is currently least favourable.

Homeostasis and Control and Coordination

A2 Level

Mục tiêu Unit: Nguyên lý hằng định nội môi và phản hồi âm (negative feedback); điều hòa đường huyết bằng insulin/glucagon và bệnh đái tháo đường; cấu tạo thận, quá trình siêu lọc, tái hấp thu chọn lọc, cơ chế nhân ngược dòng ở quai Henle; vai trò của ADH trong điều hòa áp suất thẩm thấu; điều hòa thân nhiệt; điện thế nghỉ, điện thế hoạt động và dẫn truyền xung thần kinh (kể cả dẫn truyền nhảy cóc); synapse hóa học và cộng hưởng (summation); so sánh hệ thần kinh với hệ nội tiết; tính hướng động ở thực vật và vai trò của auxin.

11.1 Part A: Homeostasis

11.1.1 The principle of homeostasis and negative feedback

Homeostasis is the maintenance of a constant internal environment (e.g. blood glucose concentration, water potential, temperature, pH, carbon dioxide concentration) despite changes in the external environment. A stable internal environment keeps the conditions around cells within the narrow range in which enzymes and other proteins function efficiently, so homeostasis is essential for normal metabolism and survival.

Nearly all homeostatic mechanisms work by **negative feedback**. A **receptor** detects a deviation of some variable away from its normal value (the **set point**). Information about this deviation is passed to a **coordinator** (a processing centre — often part of the brain, or an endocrine gland/tissue) which compares the detected value with the set point and, if a correction is needed, sends information to an **effector** (a muscle or gland). The effector brings about a response that moves the variable back *toward* the set point. Once the variable returns to normal, the original stimulus is removed, so the corrective response itself switches off — this is what makes the feedback *negative*: the response always acts to oppose (cancel out) the original change.

The negative feedback loop

Stimulus (variable deviates from set point) → **receptor** detects the deviation → **coordinator** (processing centre) compares to set point → **effector** produces a corrective response → variable returns toward the set point → original stimulus is removed. Because negative feedback constantly corrects deviations in *both* directions (too high *and* too low), the variable oscillates in a narrow band around the set point rather than drifting away from it.

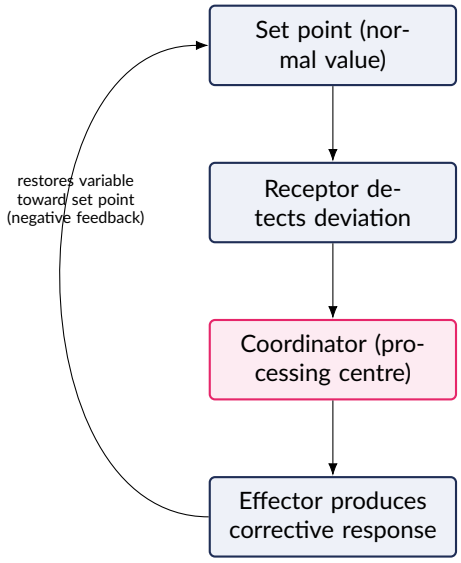

Figure 1. The general negative feedback loop that underlies homeostasis.

Most homeostatic control is negative feedback, but a small number of physiological events use **positive feedback**, in which the response *amplifies* the original change rather than reversing it. Positive feedback is not self-correcting — it drives a variable rapidly and increasingly away from its starting value until some other process halts it. Two important examples: (1) during **childbirth**, stretching of the cervix stimulates release of the hormone oxytocin, which strengthens uterine contractions; stronger contractions stretch the cervix further, releasing still more oxytocin — this cycle amplifies until the baby is delivered, at which point the stretching stimulus is removed and the cycle stops; (2) during **blood clotting**, activated platelets release chemicals that activate more platelets and clotting factors, rapidly amplifying clot formation at a wound site until the mesh of fibrin is complete.

VN **GIẢI THÍCH TIẾNG VIỆT**

Hằng định nội môi (homeostasis) là duy trì môi trường bên trong cơ thể ổn định dù môi trường bên ngoài thay đổi, đảm bảo enzyme hoạt động hiệu quả. Cơ chế chính là **phản hồi âm (negative feedback)**: thụ thể phát hiện sai lệch → trung tâm điều phối so sánh với giá trị chuẩn → cơ quan đáp ứng tạo ra phản ứng điều chỉnh, kéo biến số trở về mức bình thường — phản ứng luôn có xu hướng **triệt tiêu** kích thích ban đầu. Ngược lại, **phản hồi dương (positive feedback)** khuếch đại sự thay đổi thay vì triệt tiêu nó — ví dụ điển hình là quá trình sinh nở (oxytocin làm co tử cung mạnh hơn, kích thích tiết thêm oxytocin) và quá trình đông máu (tiểu cầu hoạt hóa kích hoạt thêm tiểu cầu khác).

11.1.2 Blood glucose regulation

Blood glucose concentration in a healthy person is normally kept within a narrow range (about 4–6 mmol dm^{-3} when fasting) by the antagonistic actions of two pancreatic hormones. The **islets of Langerhans** are clusters of endocrine cells scattered through the pancreas; within each islet, β **(beta) cells** secrete **insulin** and α **(alpha) cells** secrete **glucagon**. Both cell types act as the receptor *and* part of the coordinating mechanism, since they directly detect blood glucose concentration.

After a meal, blood glucose rises. This is detected by β cells, which respond by secreting insulin into the blood. Insulin binds to receptors on liver and muscle cells (and adipose tissue) and has several effects: it increases the rate of glucose uptake into these cells (by stimulating insertion of glucose transporter proteins into the cell surface membrane); it activates the enzymes that convert glucose to glycogen for storage in the liver and muscle (**glycogenesis**); and it increases the rate of respiration of glucose. All of these effects lower blood glucose concentration back toward the set point.

Between meals, or during exercise/fasting, blood glucose falls. This is detected by α cells, which

respond by secreting glucagon. Glucagon acts mainly on the liver, where it stimulates the breakdown of stored glycogen back to glucose (**glycogenolysis**) and stimulates the production of new glucose from non-carbohydrate sources such as amino acids and glycerol (**gluconeogenesis**). Both effects release glucose into the blood, raising blood glucose concentration back toward the set point. Insulin and glucagon are thus **antagonistic** hormones, and together they form a negative feedback system that keeps blood glucose within narrow limits regardless of whether a person has just eaten or has been fasting/exercising.

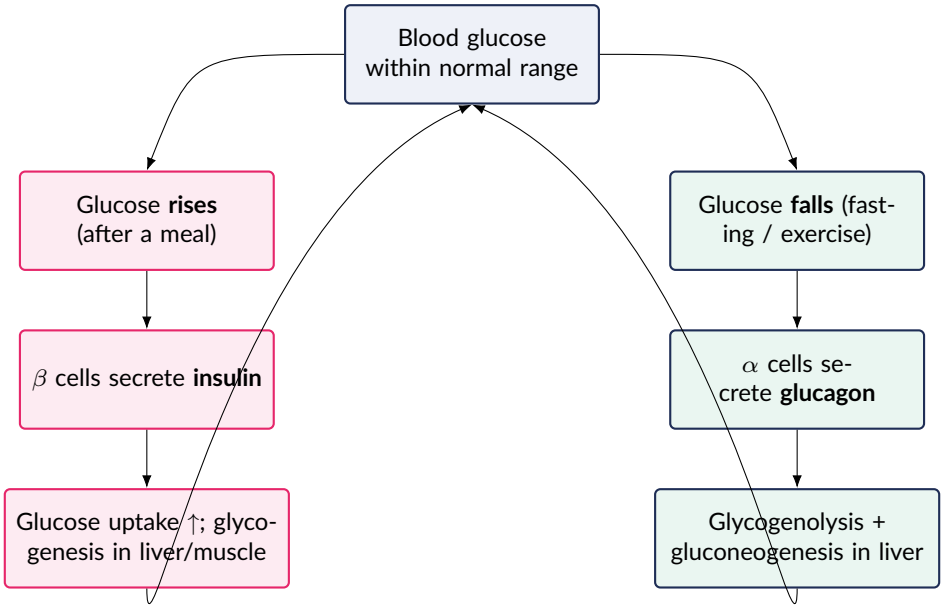

Figure 2. The insulin/glucagon negative feedback loop controlling blood glucose concentration.

GIẢI THÍCH TIẾNG VIỆT VN

Đảo tụy Langerhans gồm tế bào β tiết **insulin** (khi đường huyết tăng — sau bữa ăn) và tế bào α tiết **glucagon** (khi đường huyết giảm — lúc đói/vận động). Insulin thúc đẩy tế bào gan/cơ hấp thu glucose và chuyển glucose thành glycogen dự trữ (**glycogenesis**), làm giảm đường huyết. Glucagon thúc đẩy gan phân giải glycogen thành glucose (**glycogenolysis**) và tổng hợp glucose mới từ nguồn phi carbohydrate (**gluconeogenesis**), làm tăng đường huyết. Hai hormone này đối kháng nhau, tạo thành vòng phản hồi âm giữ đường huyết ổn định.

Worked example: blood glucose after a meal

The table shows blood glucose concentration (mmol dm^{-3}) measured at intervals after an identical test meal in three individuals: a healthy (non-diabetic) person, a person with untreated Type 1 diabetes, and a person with untreated Type 2 diabetes.

Time (min)	0	30	60	90	120	180
Healthy	5.0	6.5	7.2	6.0	5.2	5.0
Type 1 (untreated)	9.0	13.0	16.0	17.0	17.5	17.0
Type 2 (untreated)	7.0	10.0	12.0	11.0	9.5	8.0

(a) Explain the shape of the healthy curve. *(b)* Explain why the Type 1 curve neither peaks as sharply nor returns to a normal baseline within the time shown. *(c)* Explain why the Type 2 curve is elevated throughout but does begin to fall.

(a) In the healthy individual, rising glucose after the meal is detected by β cells, which secrete insulin; insulin stimulates glucose uptake into liver/muscle cells and glycogenesis, so glucose is quickly cleared from the blood and returns to the fasting baseline (about 5 mmol dm^{-3}) within roughly two hours — a normal, tightly-controlled negative feedback response.
(b) In Type 1 diabetes, autoimmune destruction of β cells means little or no insulin is secreted even though glucose keeps rising. Because there is no functional signal to trigger glucose uptake/glycogenesis, blood glucose keeps climbing (hyperglycaemia) and remains persistently very high rather than returning to baseline within the observed period.
(c) In Type 2 diabetes, insulin is still secreted (the fasting value here, 7.0, is only mildly raised), but target cells have reduced sensitivity to insulin (receptor downregulation/insulin resistance), so the same insulin concentration produces a weaker, slower uptake response — glucose rises further than in a healthy person and is cleared only slowly and incompletely.

Type 1 diabetes: autoimmune destruction of pancreatic β cells → little/no insulin produced → treated with regular insulin injections (cannot be managed by diet alone). **Type 2 diabetes:** target cells become less responsive to insulin (insulin resistance/receptor downregulation), often associated with obesity/inactivity → initially manageable with diet and exercise, but may progress to require oral medication or insulin.

Worked example: diagnosing diabetes type from blood data

A patient's fasting blood glucose is 6.0 mmol dm^{-3} (mildly elevated above the normal 4–6 range) and their fasting blood insulin concentration is measured at roughly three times the normal fasting level. After an oral glucose tolerance test, their blood glucose rises unusually high and returns to baseline only slowly over several hours. Identify the most likely condition and justify your answer.

Insulin is clearly being secreted, and at an elevated concentration — this rules out Type 1 diabetes, in which insulin would be absent or very low regardless of glucose challenge. Since insulin is present in *above-normal* amounts yet blood glucose still rises excessively and clears slowly, the target cells (liver/muscle) must be responding poorly to insulin — the pancreas is compensating by secreting more insulin than usual, but with reduced effect. This pattern (high/normal insulin plus poor glucose clearance) is characteristic of **Type 2 diabetes** (insulin resistance).

11.1.3 The kidney: gross structure and the nephron

The kidney's gross structure, seen in longitudinal section, shows an outer **cortex** (contains the Bowman's capsules/glomeruli and the convoluted tubules), an inner **medulla** (contains the loops of Henle and collecting ducts, arranged in cone-shaped pyramids), and a central **pelvis** which collects urine draining from the collecting ducts and funnels it into the **ureter**, the tube carrying urine to the bladder.

Each kidney contains about a million functional units called **nephrons**. A nephron begins at the **Bowman's capsule**, a cup-shaped structure that encloses a knot of capillaries called the **glomerulus**. Blood enters the glomerulus via a wide **afferent arteriole** and leaves via a narrower **efferent arteriole**. The capsule leads into the **proximal convoluted tubule (PCT)**, then the **loop of Henle** (with a descending limb running down into the medulla and an ascending limb running back up), then the **distal convoluted tubule (DCT)**, which drains into a **collecting duct**. The collecting duct runs back down through the medulla to the pelvis.

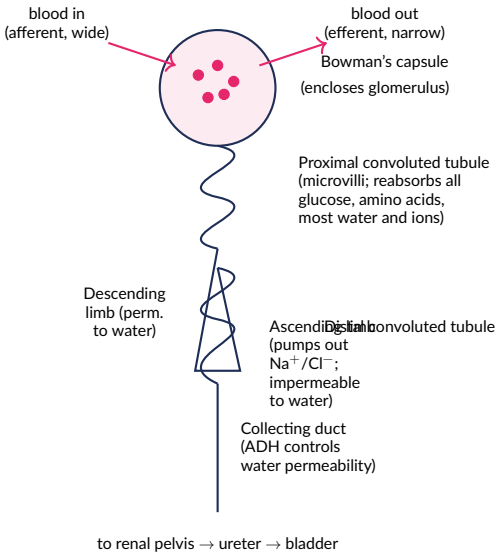

Figure 3. Structure of a nephron. Ultrafiltration occurs at the glomerulus/Bowman's capsule; selective reabsorption occurs mainly in the proximal tubule; the loop of Henle sets up an osmotic gradient in the medulla used to concentrate urine at the collecting duct.

11.1.4 Ultrafiltration and selective reabsorption

Ultrafiltration occurs at the glomerulus. Because the afferent arteriole is wider than the efferent arteriole, a high hydrostatic (blood) pressure builds up inside the glomerular capillaries. This pressure forces small dissolved molecules and ions in the blood plasma (water, glucose, amino acids, urea, salts) out of the blood, across three layers — the **fenestrated (pored) capillary endothelium**, the **basement membrane** (a molecular sieve that excludes large molecules) and the **podocytes** (specialised epithelial cells of the capsule wall, with foot-like projections leaving filtration slits) — and into the space inside the Bowman's capsule. Red blood cells, white blood cells, platelets and large plasma proteins are too large to cross the basement membrane and remain in the blood; the fluid that does cross is called the **glomerular filtrate**.

As the filtrate flows along the **proximal convoluted tubule**, **selective reabsorption** returns useful substances to the blood. All the glucose and amino acids in the filtrate are normally reabsorbed here, along with most of the water and many ions. Reabsorption of glucose and amino acids occurs by **co-transport**: a sodium-potassium pump on the basal membrane of the tubule cells actively pumps Na^+ out into the blood, maintaining a low intracellular Na^+ concentration; this allows Na^+ to diffuse back into the cell down its concentration gradient through co-transporter proteins on the microvillus (apical) membrane, and this movement is coupled to the movement of glucose or amino acids into the cell against their own concentration gradient. Glucose/amino acids then diffuse out of the cell into the blood. Water follows by osmosis, since removing solutes from the tubule fluid lowers its water potential relative to the blood. The proximal tubule's epithelium has a dense brush border of **microvilli**, greatly increasing its surface area for these transport processes, and its cells contain many mitochondria to supply ATP for active transport.

Worked example: filtered glucose load and glucosuria

Plasma glucose concentration is normally about 5 mmol dm^{-3}, and GFR is approximately 180 dm^3/day. *(a)* Calculate the mass of glucose filtered into the nephrons per day (relative molecular mass of glucose $= 180$ g mol^{-1}). *(b)* Explain why essentially none of this glucose normally appears in the urine, and suggest why glucose can appear in the urine (glucosuria) in poorly-controlled diabetes.

(a) Amount filtered $= 5$ mmol dm^{-3} $\times$ 180 dm^3 $= 900$ mmol $= 0.9$ mol per day. Mass $= 0.9 \times 180 =$ **162** g glucose filtered per day.

(b) Normally, essentially all of this filtered glucose is reabsorbed in the proximal convoluted tubule by co-transport with Na^+, so almost none remains in the tubule fluid by the time it reaches the collecting duct. In poorly-controlled diabetes (very high blood/filtrate glucose concentration), the amount of glucose filtered can exceed the maximum rate at which the co-transporter proteins can reabsorb it (the reabsorption capacity is saturated); the excess glucose that cannot be reabsorbed remains in the filtrate and is excreted in the urine — glucosuria, a classic diagnostic sign of diabetes mellitus.

(!) Lỗi thường gặp: Đừng nhầm giữa **siêu lọc** (ultrafiltration — quá trình vật lý dựa vào áp suất thủy tĩnh cao, không chọn lọc theo loại phân tử mà chỉ theo **kích thước**) với **tái hấp thu chọn lọc** (selective reabsorption — quá trình sinh học chủ động, có tính chọn lọc theo **loại chất**, ví dụ glucose/amino acid bình thường được tái hấp thu 100%). Protein huyết tương và tế bào máu không lọt qua màng đáy vì **kích thước quá lớn**, không phải vì cơ thể "chọn" giữ lại chúng.

11.1.5 The loop of Henle and the countercurrent multiplier

The loop of Henle allows mammals to produce urine that is more concentrated than blood plasma, conserving water. It works as a **countercurrent multiplier**: fluid flows down the descending limb and back up the ascending limb in opposite directions, and the two limbs have different, complementary permeability properties.

The **descending limb** is permeable to water but relatively impermeable to salt. As filtrate flows down into the increasingly salty medulla, water leaves the descending limb by osmosis into the surrounding tissue, so the fluid inside the tubule becomes progressively more concentrated as it approaches the bottom of the loop. The **ascending limb** is impermeable to water but actively pumps Na^+ and Cl^- ions out into the surrounding medulla tissue. Because water cannot follow these ions out of the ascending limb, this active pumping steadily raises the salt concentration of the medulla tissue itself — and because the two limbs run side-by-side in opposite directions (countercurrent), the effect is repeatedly reinforced ("multiplied") along the length of the loop, producing a large osmotic gradient that increases from the cortex–medulla boundary (about 300 mOsm dm^{-3}, similar to blood plasma) down to the tip of the medulla (up to about 1200 mOsm dm^{-3} in humans).

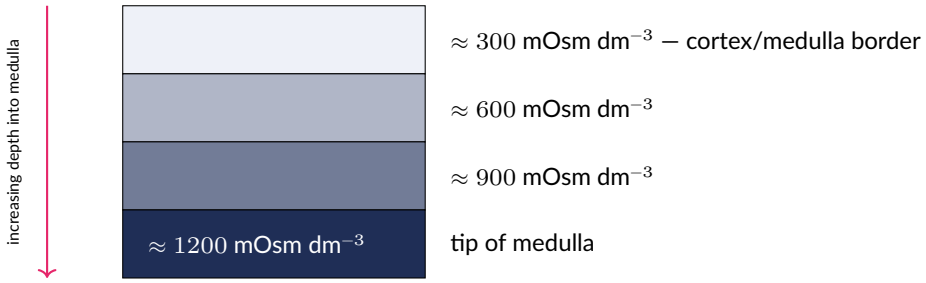

Figure 4. The osmotic (salt concentration) gradient built up in the medulla by the countercurrent multiplier — steepest at the tip of a long loop of Henle.

This steep osmotic gradient in the medullary tissue is what later allows water to be reabsorbed from the **collecting duct** (under the control of ADH, see below), since the collecting duct passes back down through this same increasingly concentrated tissue on its way to the pelvis. Animals adapted to arid environments (e.g. desert rodents) have unusually long loops of Henle relative to kidney size, producing a much steeper medullary gradient and highly concentrated urine, which conserves water; aquatic mammals such as beavers have short loops and produce comparatively dilute urine, since water conservation is not a priority for them.

Worked example: countercurrent gradient and habitat

A desert-adapted rodent has loops of Henle that extend much deeper into the medulla than those of a beaver. Explain how this difference relates to each animal's water balance.

A longer loop of Henle means the ascending limb pumps Na^+/Cl^- out over a greater length, and the descending limb loses water over a greater length, so the countercurrent multiplier builds up a much steeper, deeper osmotic gradient in the medulla. When ADH acts on the collecting duct, this steeper gradient draws far more water out of the collecting duct fluid by osmosis, producing very concentrated urine and minimising water loss — an adaptation to living in an environment with little available water. The beaver, which has ready access to water, has a shorter loop, a shallower medullary gradient, and produces more dilute urine, since conserving water is less critical for it.

Worked example: glomerular filtration rate and urine output

A person's glomerular filtration rate (GFR) is approximately 180 dm^3 per day, and about 99% of the water in this filtrate is normally reabsorbed (mainly in the proximal tubule and collecting duct). Estimate the daily volume of urine produced.

Urine volume $= 180 \times (1 - 0.99) = 180 \times 0.01 =$ **1.8** dm^3/day — a realistic daily urine output, illustrating how selective reabsorption (mostly PCT) and final fine control (collecting duct, under ADH) together recover almost all of the 180 dm^3 that is filtered.

11.1.6 Osmoregulation: ADH and negative feedback

Osmoregulation is the control of the water potential of the blood and body fluids. **Osmoreceptor** cells in the hypothalamus continuously monitor the water potential of the blood as it passes through the brain. If the blood's water potential falls (i.e. the blood becomes more concentrated — for example after sweating heavily, eating salty food, or not drinking enough), osmoreceptor cells lose water by osmosis and shrink, which stimulates neurosecretory cells to release more **antidiuretic hormone (ADH)** from the **posterior pituitary gland** into the blood. ADH travels in the blood to the kidney, where it binds to receptors on the cells of the **collecting duct**. This triggers vesicles containing **aquaporin** (water channel) proteins to fuse with the apical (luminal) cell membrane, increasing the duct's permeability to water. As the collecting duct fluid passes through the increasingly salty medulla (built up by the countercurrent multiplier), more water is drawn out of it by osmosis and reabsorbed into the blood — so more water is retained, blood water potential rises back toward normal, and a small volume of concentrated urine is produced. As blood water potential returns to normal, osmoreceptor stimulation and ADH release both decrease — a classic negative feedback loop.

If blood water potential rises instead (e.g. after drinking a large volume of water), osmoreceptors are stimulated less, ADH secretion falls, fewer aquaporins are inserted into the collecting duct, less water is reabsorbed, and a large volume of dilute urine is produced, lowering blood water potential back toward normal.

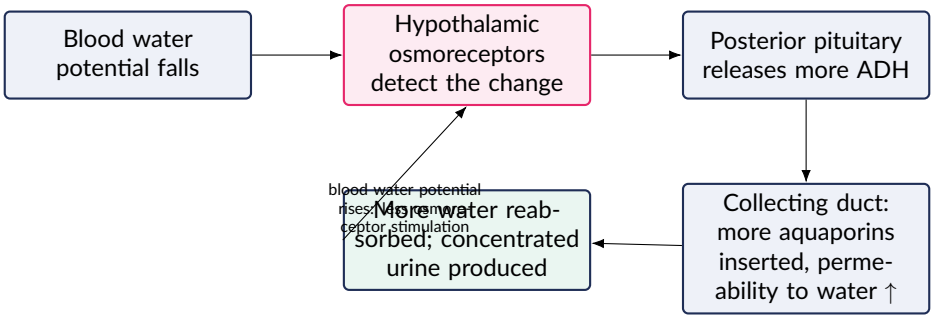

Figure 5. ADH negative feedback loop controlling blood water potential.

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Thụ thể áp suất thẩm thấu (osmoreceptor) ở vùng dưới đồi phát hiện khi máu bị "đặc" lại (thế nước giảm) → kích thích thùy sau tuyến yên tiết nhiều **ADH** hơn → ADH làm tăng số kênh aquaporin ở ống góp → tăng tái hấp thu nước → nước tiểu cô đặc hơn, thể tích ít hơn → thế nước máu trở lại bình thường, giảm tiết ADH — đây là vòng **phản hồi âm** kinh điển. Ngược lại, uống nhiều nước làm thế nước máu tăng → ức chế tiết ADH → nước tiểu loãng, thể tích nhiều.

Worked example: water deprivation

A person is deprived of water for several hours. Predict and explain the changes in (a) ADH concentration in the blood, (b) permeability of the collecting duct, (c) the volume and concentration of urine produced.

As water intake stops, blood water potential gradually falls (solutes become relatively more concentrated). **(a)** Hypothalamic osmoreceptors detect this fall and stimulate greater release of ADH from the posterior pituitary, so blood ADH concentration **rises**. **(b)** The extra ADH causes more aquaporin channels to be inserted into the collecting duct membrane, so its permeability to water **increases**. **(c)** As the collecting duct fluid passes through the osmotic gradient in the medulla, more water is reabsorbed into the blood; urine volume therefore **decreases** and urine becomes more **concentrated** (a smaller volume containing a similar mass of solutes) — helping to restore blood water potential toward normal.

Worked example: alcohol and ADH

Explain why drinking alcohol tends to produce a larger volume of dilute urine than the volume of liquid consumed, and why this can contribute to dehydration.

Alcohol **inhibits** the release of ADH from the posterior pituitary, regardless of the actual water potential of the blood. With less ADH circulating, fewer aquaporins are inserted into the collecting duct membrane, so its permeability to water is reduced; much less water is reabsorbed from the collecting duct as it passes through the medulla, so a larger-than-normal volume of dilute urine is produced. Because this fluid loss occurs even though blood water potential has not actually risen enough to justify it, the net effect can be a loss of body water greater than the volume of alcoholic drink consumed — contributing to dehydration (and effects such as thirst and headache the next day).

11.1.7 Thermoregulation

Mammals maintain a fairly constant core body temperature (about 37 °C in humans) regardless of the external temperature, using the **hypothalamus** as the thermoregulatory centre. The hypothalamus contains thermoreceptor cells that monitor the temperature of blood flowing through the brain, and it also receives input from peripheral thermoreceptors in the skin. If body temperature deviates from the set point, the hypothalamus coordinates a set of effector responses that use negative feedback to restore normal temperature.

If body temperature rises above normal, **heat loss** mechanisms are activated: **vasodilation** of arterioles supplying skin capillaries increases blood flow near the skin surface, so more heat is lost to the surroundings by radiation and convection; **sweating** increases, and evaporation of sweat from the skin surface removes latent heat, cooling the skin; **hair/fur is flattened** (erector pili muscles relax), reducing the layer of insulating air trapped against the skin and so increasing heat loss.

If body temperature falls below normal, **heat gain/conservation** mechanisms are activated: **vasoconstriction** of skin arterioles reduces blood flow near the surface, reducing heat loss; **shivering** — involuntary, rapid contraction of skeletal muscles — increases the rate of respiration, releasing heat as a by-product; **hair/fur is erected** (erector pili muscles contract), trapping a thicker layer of insulating air against the skin (much more effective in furred mammals than in humans); **behavioural responses** such as seeking shelter, curling up to reduce surface area, or basking in the sun also help conserve or gain heat.

	Body temperature too high	**Body temperature too low**
Blood vessels	Vasodilation — more blood flow near skin, more heat lost	Vasoconstriction — less blood flow near skin, less heat lost
Sweat glands	Sweating increases; evaporation removes heat	Sweating decreases
Hair/fur (erector pili muscles)	Relax — hair flattens, less insulation	Contract — hair stands up (pilo-erection), traps insulating air
Skeletal muscle	—	Shivering — increased respiration releases heat

Table 1. Thermoregulatory effector responses controlled by the hypothalamus, both operating by negative feedback around the $37\,^{\circ}$C set point.

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Vùng dưới đồi (hypothalamus) là trung tâm điều nhiệt: khi thân nhiệt tăng, cơ thể **giãn mạch da**, **tăng tiết mồ hôi**, **xẹp lông** để tăng thải nhiệt; khi thân nhiệt giảm, cơ thể **co mạch da**, **run cơ** (sinh nhiệt qua hô hấp tế bào), **dựng lông** để giữ nhiệt, và có thể có phản ứng tập tính (tìm nơi trú ẩn, cuộn tròn cơ thể). Tất cả đều là ví dụ của **phản hồi âm**, đưa thân nhiệt về mức chuẩn khoảng $37\,^{\circ}$C.

11.2 Part B: Control and Coordination

11.2.1 The nervous system: organisation and the reflex arc

The **nervous system** is organised into the **central nervous system (CNS)** — the brain and spinal cord, where information is processed and coordinated — and the **peripheral nervous system (PNS)** — the nerves connecting the CNS to receptors and effectors throughout the body. Information travels along **sensory neurones** from receptors toward the CNS, is processed (often by **relay/intermediate neurones** within the CNS), and travels back out along **motor neurones** to effectors (muscles or glands).

A **reflex arc** is a fast, automatic, involuntary response to a stimulus, following a fixed pathway: **stimulus** → **receptor** → **sensory neurone** → **relay neurone** (in the spinal cord) → **motor neurone** → **effector** → **response**. Because the pathway is short (often involving only a few synapses, sometimes bypassing the brain entirely) reflexes are extremely fast, and because they do not require conscious decision-making, they provide rapid protection from potentially harmful stimuli (e.g. withdrawing a hand from a hot object) before the danger can cause serious damage.

Reflex arc order: **stimulus** → **receptor** → **sensory neurone** → **relay neurone** → **motor neurone** → **effector** → **response**. The relay neurone (in the spinal cord/CNS) is what allows the response to bypass conscious processing in the brain — this is what makes reflexes so fast, giving a crucial protective advantage.

11.2.2 Neurone structure

A typical **motor neurone** has a **cell body** containing the nucleus and most organelles, with many short, branched **dendrites** that receive impulses from other neurones and carry them toward the cell body. A single long **axon** carries impulses away from the cell body toward the effector. Many axons are wrapped in a **myelin sheath**, formed by **Schwann cells** that wrap tightly around the axon in a spiral, leaving small unmyelinated gaps called **nodes of Ranvier** exposed at regular intervals. The myelin sheath electrically insulates the axon membrane, so ion movement (and therefore the action potential) can only occur at the nodes of Ranvier — this produces **saltatory conduction**, in which the impulse appears to "jump" from node to node rather than travelling continuously along the whole membrane, greatly increasing conduction speed compared with an unmyelinated axon of the same diameter.

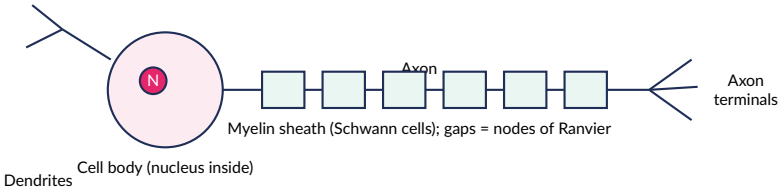

Figure 6. A myelinated motor neurone. Impulses are regenerated only at the nodes of Ranvier, producing rapid saltatory conduction.

11.2.3 Resting potential

When a neurone is not conducting an impulse, the inside of the axon membrane is maintained at about -70 mV relative to the outside — the **resting potential**. This is maintained mainly by the **sodium–potassium pump**, which uses ATP to actively transport $3\,Na^+$ ions out of the axon for every $2\,K^+$ ions pumped in. In addition, the membrane has more open K^+ "leak" channels than Na^+ channels, so K^+ diffuses out of the cell more readily than Na^+ can diffuse in, and negatively charged proteins inside the axon (too large to cross the membrane) contribute further negative charge. The combined effect is that the inside of the axon is left more negative than the outside.

11.2.4 The action potential

If a stimulus is large enough to depolarise the membrane to a **threshold** value, an **action potential** is triggered. **Depolarisation**: voltage-gated Na^+ channels open, and Na^+ rushes into the axon down its steep electrochemical gradient, making the inside of the membrane rapidly more positive (rising to about $+40$ mV). **Repolarisation**: at the peak, the voltage-gated Na^+ channels close (inactivate) and voltage-gated K^+ channels open; K^+ diffuses out of the axon down its gradient, making the inside progressively more negative again. **Hyperpolarisation**: because the K^+ channels close slightly later than ideal, slightly too much K^+ leaves, briefly making the membrane potential more negative than the normal resting value (an "undershoot") before the sodium–potassium pump restores the resting potential.

During and shortly after an action potential, the membrane cannot be re-stimulated to fire again — the **refractory period**. During the **absolute refractory period**, the Na^+ channels are inactivated and cannot reopen no matter how strong a new stimulus is; during the following **relative refractory period**, a new action potential can be triggered but only by a stronger-than-normal stimulus (as K^+ channels are still open, hyperpolarising the membrane). The refractory period is functionally important for two reasons: it ensures the action potential can only travel in **one direction** (the region just fired cannot re-fire, so only the region ahead, which is still at rest, can be stimulated next), and it sets an upper limit on the **maximum frequency** at which a neurone can fire.

Every action potential that is triggered reaches the same peak size (about $+40$ mV) regardless of the strength of the stimulus that triggered it — the **all-or-nothing principle**. A stimulus below threshold produces no action potential at all; a stimulus at or above threshold always produces a full-sized action potential. Stimulus intensity is instead encoded by the **frequency** of action potentials

(a stronger stimulus produces more impulses per second, not bigger ones) and by the number of neurones recruited.

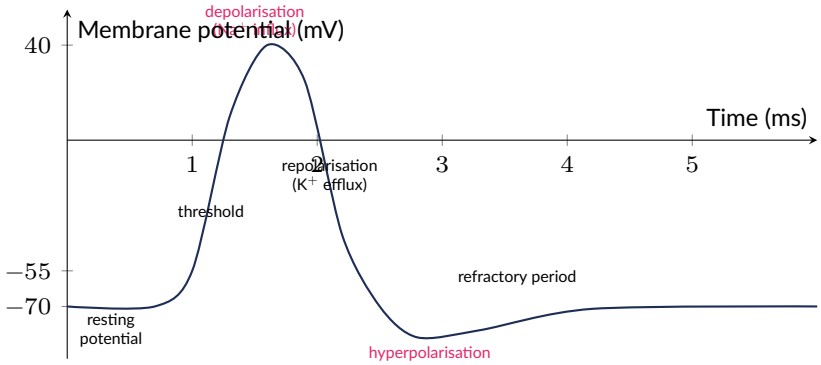

Figure 7. An action potential: membrane potential against time, showing resting potential, threshold, depolarisation, repolarisation, hyperpolarisation (undershoot) and the refractory period.

Worked example: reading an action potential trace

A recording shows the following membrane potentials at an axon membrane: $t = 0$ ms: -70 mV; $t = 1$ ms: -55 mV; $t = 1.5$ ms: $+35$ mV; $t = 2.2$ ms: -45 mV; $t = 2.8$ ms: -82 mV; $t = 4$ ms: -70 mV. Identify the phase of the action potential occurring at each time.

$t = 0$ ms (-70 mV): **resting potential**. $t = 1$ ms (-55 mV): membrane has just reached **threshold**, voltage-gated Na^+ channels beginning to open. $t = 1.5$ ms ($+35$ mV, near the peak): **depolarisation** almost complete, most Na^+ channels open. $t = 2.2$ ms (-45 mV, falling from the peak): **repolarisation**, Na^+ channels inactivated and K^+ channels open. $t = 2.8$ ms (-82 mV, below resting value): **hyperpolarisation** (undershoot) — this and the following few milliseconds are the **refractory period**, during which a new action potential cannot easily be triggered. $t = 4$ ms (-70 mV): resting potential has been restored (via the Na^+/K^+ pump) and the membrane is excitable again.

Worked example: refractory period and maximum firing frequency

The absolute refractory period of a particular axon lasts 2 ms. Calculate the maximum possible frequency at which this axon can fire action potentials.

If each action potential (plus its refractory period) must be at least 2 ms apart, the maximum number of impulses per second is

$$f_{\text{max}} = \frac{1}{2 \times 10^{-3}\ \text{s}} = \textbf{500}\ \text{Hz}\ (\textbf{500}\ \text{impulses per second}).$$

This illustrates why the refractory period sets an upper limit on firing frequency, and why stimulus intensity above this ceiling can no longer be encoded by frequency alone.

Worked example: saltatory conduction and reflex speed

A reflex arc pathway is 1.5 m long. Along a myelinated axon the impulse travels at $100\ \text{m s}^{-1}$; along an unmyelinated axon of the same length it travels at only $5\ \text{m s}^{-1}$. Compare the time taken for the impulse to travel the pathway in each case.

Myelinated: $t = \dfrac{1.5}{100} = 0.015$ s $= 15$ ms. Unmyelinated: $t = \dfrac{1.5}{5} = 0.3$ s $= 300$ ms. The myelinated pathway is 20 times faster — saltatory conduction (impulses jumping between nodes of

Ranvier, rather than triggering the whole membrane continuously) is essential for the very fast responses needed in protective reflexes.

11.2.5 Synaptic transmission

A **synapse** is a junction between two neurones (or between a neurone and an effector), separated by a narrow gap, the **synaptic cleft**. Transmission across a chemical synapse follows a fixed sequence: an arriving action potential depolarises the **presynaptic membrane**, opening **voltage-gated Ca^{2+} channels**; Ca^{2+} diffuses into the presynaptic knob, causing **synaptic vesicles** containing neurotransmitter (e.g. **acetylcholine**) to move to and fuse with the presynaptic membrane, releasing their contents into the synaptic cleft by **exocytosis**. The neurotransmitter diffuses across the cleft and binds to specific receptor proteins on the **postsynaptic membrane**, which are also **ligand-gated ion channels**: binding causes the channel to open, allowing ions (e.g. Na^{+}) to move across the postsynaptic membrane. If this depolarises the postsynaptic membrane, it produces an **excitatory postsynaptic potential (EPSP)**, making an action potential more likely; if it hyperpolarises the membrane (e.g. by opening Cl^{-} channels), it produces an **inhibitory postsynaptic potential (IPSP)**, making an action potential less likely. Finally, the neurotransmitter is rapidly broken down or removed — acetylcholine, for example, is hydrolysed by the enzyme **acetylcholinesterase** into choline and ethanoic acid, which diffuse back into the presynaptic knob to be resynthesised into acetylcholine — preventing continuous, unwanted stimulation of the postsynaptic cell.

Because neurotransmitter is only released from the presynaptic side and receptors are only present on the postsynaptic side, transmission across a chemical synapse can only occur in **one direction**.

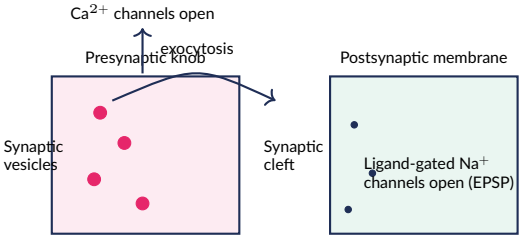

Figure 8. A chemical synapse. Ca^{2+} influx triggers exocytosis of neurotransmitter; receptor specificity and one-way vesicle release ensure transmission is one-directional.

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Tại synapse hóa học: xung thần kinh đến → mở kênh Ca^{2+} có cổng điện thế → Ca^{2+} vào làm túi synapse gắn với màng trước, giải phóng chất dẫn truyền thần kinh (ví dụ acetylcholine) ra khe synapse bằng **xuất bào** → chất dẫn truyền gắn thụ thể ở màng sau (là kênh ion có cổng phối tử) → mở kênh ion, gây điện thế hưng phấn (EPSP) hoặc ức chế (IPSP) → chất dẫn truyền bị phân giải/loại bỏ (ví dụ bởi acetylcholinesterase) để tránh kích thích liên tục. Vì chỉ có màng trước giải phóng và chỉ màng sau có thụ thể, xung chỉ truyền **một chiều**.

11.2.6 Synaptic summation

A single presynaptic impulse often releases too little neurotransmitter to depolarise the postsynaptic membrane all the way to threshold on its own. **Summation** allows multiple sub-threshold inputs to combine and reach threshold. In **temporal summation**, a single presynaptic neurone fires several action potentials in rapid succession; each releases neurotransmitter that produces a small EPSP, and if these EPSPs arrive close enough together in time, they add up (summate) at the postsynaptic membrane before the first has fully decayed, eventually reaching threshold and triggering a postsynaptic action potential. In **spatial summation**, several different presynaptic neurones, each making

a synapse onto the same postsynaptic cell, fire simultaneously (or nearly so); their individual subthreshold EPSPs add together at different points on the postsynaptic membrane, and the combined depolarisation can reach threshold even though no single input could do so alone. Summation of EPSPs and IPSPs together allows a postsynaptic neurone to integrate many simultaneous excitatory and inhibitory inputs, effectively acting as a decision-making point in the nervous system.

Worked example: synaptic summation

A single presynaptic impulse at a particular synapse produces an EPSP of $+5$ mV. The postsynaptic membrane rests at -70 mV and has a threshold of -55 mV. *(a)* Would a single impulse trigger a postsynaptic action potential? *(b)* Explain, with reference to summation, how three impulses arriving in rapid succession from the same presynaptic neurone might trigger one.

(a) A single EPSP of $+5$ mV would only depolarise the membrane to $-70 + 5 = -65$ mV, which is still below the -55 mV threshold, so **no** action potential is triggered by one impulse alone.

(b) If three impulses arrive in rapid succession (temporal summation) before each EPSP has fully decayed, their effects add together: three EPSPs of $+5$ mV give a combined depolarisation of approximately $+15$ mV, bringing the membrane potential to roughly $-70 + 15 = -55$ mV — reaching threshold and triggering a postsynaptic action potential. (The same threshold could also be reached by spatial summation, if three different presynaptic neurones synapsing on the same cell fired together instead.)

11.2.7 Nervous versus hormonal communication

Nervous and hormonal (endocrine) communication are the two main ways body systems coordinate responses; they differ in speed, duration and specificity.

	Nervous communication	**Hormonal (endocrine) communication**
Signal	Electrical impulse (action potential) along a neurone, chemical only across synapses	Chemical messenger (hormone) secreted directly into the blood
Speed of onset	Very fast (milliseconds)	Slower (seconds to hours)
Duration of effect	Brief, short-lived	Longer-lasting
Target/specificity	Precise — a specific effector connected by a neurone	Widespread — any cell in the body with matching receptors
Route of transmission	Along dedicated neurone pathways	Via the bloodstream, distributed throughout the body

Table 2. Comparison of nervous and hormonal communication.

Worked example: comparing response times

A person touches a very hot object; the reflex withdrawal of the hand begins within about 0.02 s (20 ms) of the stimulus. In a separate situation, a fall in blood glucose after fasting takes several minutes before glucagon secretion has raised blood glucose significantly. Explain this large difference in timing between the two coordination systems.

The withdrawal reflex uses **nervous** communication: sensory neurone → relay neurone → motor neurone → effector, involving only electrical conduction along a few neurones and very brief chemical transmission across one or two synapses — a pathway that can be completed in milliseconds. The blood glucose response uses **hormonal** communication: α cells must synthesise and secrete glucagon into the blood, the hormone must be carried by the circulation to the liver (which may take from seconds to a minute or more depending on circulation time),

bind to receptors on liver cells, and then activate an internal enzyme cascade (glycogenolysis) before glucose is actually released into the blood in a physiologically significant amount — a multi-step process that inherently takes much longer than direct nervous transmission, even though both are examples of negative feedback control.

VN **GIẢI THÍCH TIẾNG VIỆT**

Hệ thần kinh truyền tín hiệu **điện** (điện thế hoạt động) dọc theo neuron, tác động **nhanh**, **ngắn**, và **chính xác** tới một cơ quan đích cụ thể. Hệ nội tiết truyền tín hiệu **hóa học** (hormone) qua máu, tác động **chậm hơn** nhưng **kéo dài** và **lan rộng** tới bất kỳ tế bào nào có thụ thể phù hợp. Hai hệ thống này bổ sung cho nhau trong việc điều phối hoạt động cơ thể.

11.2.8 Plant coordination: tropisms and auxin

Plants respond to directional environmental stimuli through **tropisms** — directional growth responses. **Phototropism** is growth in response to the direction of light (shoots typically show positive phototropism, growing toward light); **gravitropism** is growth in response to gravity (roots typically show positive gravitropism, growing downward/toward gravity; shoots typically show negative gravitropism, growing upward/away from gravity).

Tropisms are controlled by the plant hormone **auxin** (indole-3-acetic acid, IAA), which is synthesised in the tip of the shoot and diffuses down the shoot, stimulating **cell elongation**. Under a unilateral (one-sided) stimulus — unequal light or unequal gravity — auxin is transported **laterally** toward the shaded side (under unilateral light) or toward the lower side (under gravity), rather than being distributed evenly. This lateral redistribution model is known as the **Cholodny–Went hypothesis**. Because the side with the higher auxin concentration elongates more (in shoots), the shoot bends toward the light — the shaded side, which has more auxin and elongates faster, is on the outside of the resulting curve, so growth curves the tip toward the light source. In roots, cells are far more sensitive to auxin, and the same higher auxin concentration on the lower side actually **inhibits** elongation there, so the upper (less-auxin) side elongates more and the root curves downward, toward gravity.

Evidence for this model comes from classic coleoptile (young shoot) experiments. If the tip of a coleoptile is **removed (decapitated)**, growth stops almost entirely, even under unilateral light — showing that a signal from the tip, not the tip's physical presence alone, is required for growth. If a decapitated coleoptile has an **agar block** (previously in contact with an isolated tip, so it has absorbed auxin) placed centrally back on the cut stump, growth resumes evenly — showing the growth-promoting signal is a **diffusible chemical** that can pass through agar, not a physical/structural effect of the tip. If the same auxin-containing agar block is placed **off-centre** on one side of the decapitated stump (with no light present), the coleoptile bends *away* from that side, because the side under the block receives more auxin and elongates faster — confirming that unequal lateral distribution of auxin, not light itself, is the proximate cause of curvature. Finally, inserting an impermeable barrier (e.g. a thin sheet of mica) vertically through the coleoptile tip, so auxin cannot move laterally across it, abolishes bending toward unilateral light (auxin can still move downward on each side but not sideways across the barrier) — showing that light causes bending by triggering *lateral redistribution* of auxin toward the shaded side, rather than by changing the total amount of auxin made.

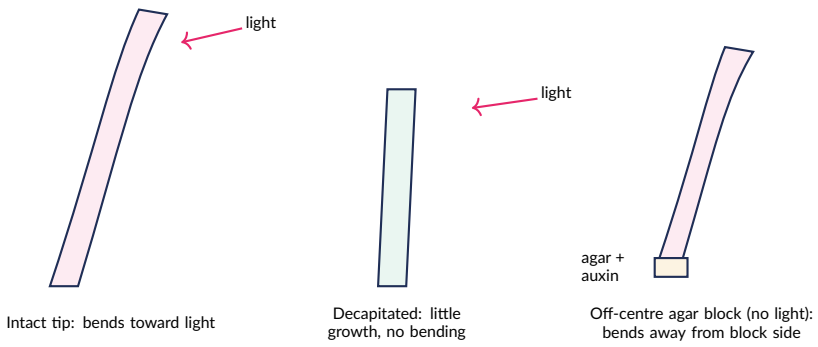

Figure 9. Classic coleoptile experiments providing evidence for auxin-mediated phototropism (Cholodny–Went model).

VN **GIẢI THÍCH TIẾNG VIỆT**

Auxin (IAA) được tổng hợp ở đỉnh chồi, khuếch tán xuống, thúc đẩy **kéo dài tế bào**. Khi ánh sáng chiếu một phía, auxin được vận chuyển **ngang** sang phía **tối** (giả thuyết Cholodny–Went), làm tế bào phía tối dài ra nhanh hơn → thân uốn cong về phía ánh sáng. Ở rễ, cùng nồng độ auxin cao lại **ức chế** kéo dài, khiến rễ uốn cong theo hướng ngược lại (về phía trọng lực). Thí nghiệm cắt đỉnh chồi, thay bằng khối thạch (agar) chứa auxin đặt lệch tâm, hoặc chèn tấm chắn không thấm, đều là bằng chứng kinh điển cho vai trò của auxin.

Worked example: predicting coleoptile bending

A coleoptile is decapitated. An agar block that has absorbed auxin from an isolated tip is placed asymmetrically on the left-hand side of the cut stump. No unilateral light is present. Predict what will happen and explain why.

Auxin diffuses out of the agar block into the underlying cells on the **left** side of the stump only, since it was placed off-centre and no light-driven lateral redistribution is needed here — the asymmetric placement itself creates the unequal auxin distribution. Auxin promotes cell elongation in shoot tissue, so cells on the left side elongate faster than cells on the right (which received little or no auxin). Faster elongation on the left side pushes/curves the coleoptile toward the **right** — i.e. the coleoptile bends away from the side where the agar block was placed. This occurs even in complete darkness, confirming that it is the *distribution* of auxin (not light directly) that determines the direction of bending.

(!) Lỗi thường gặp: Đừng nhầm phản ứng của **rễ** và **thân** với auxin: cùng một nồng độ auxin cao **thúc đẩy** kéo dài tế bào ở thân nhưng lại **ức chế** kéo dài tế bào ở rễ (vì rễ nhạy cảm với auxin hơn nhiều). Đây là lý do thân hướng sáng dương/hướng đất âm còn rễ hướng sáng âm/hướng đất dương, dù cùng cơ chế phân bố auxin.

11.3 Practice questions

11.3.1 Part A: Homeostasis

Bài tập luyện tập

Define homeostasis and explain, in general terms, why negative feedback (rather than positive feedback) is the appropriate mechanism for maintaining most internal variables.

Lời giải chi tiết

Homeostasis is the maintenance of a constant internal environment despite changes in the external environment. Negative feedback is appropriate because it is **self-correcting**: any deviation from the set point (in either direction) triggers a response that opposes and cancels out that deviation, so the variable is kept oscillating within a narrow band around the set point. Positive feedback, by contrast, amplifies any deviation, driving the variable further and further from normal — useful only in the rare situations (e.g. childbirth, blood clotting) where a rapid, self-amplifying, one-off event is actually required, not for maintaining a stable internal environment.

Bài tập luyện tập

Which of the following is an example of positive, rather than negative, feedback?

(A) Insulin secretion falling once blood glucose returns to normal

(B) Sweating increasing as body temperature rises above $37\,^{\circ}$C, then decreasing again once temperature falls

(C) Stretching of the cervix during labour causing more oxytocin release, which causes stronger contractions and further cervical stretching

(D) ADH secretion decreasing once blood water potential rises to normal

Lời giải chi tiết

In labour, cervical stretching stimulates oxytocin release; oxytocin strengthens contractions, which stretch the cervix further, releasing yet more oxytocin — the response amplifies the original stimulus rather than reversing it, characteristic of **positive** feedback. **(C)**.

Bài tập luyện tập

Explain, in terms of receptors, hormones and target tissues, how a rise in blood glucose concentration after a meal is corrected.

Lời giải chi tiết

Rising blood glucose is detected by β cells in the islets of Langerhans, which respond by secreting insulin into the blood. Insulin binds to receptors on liver and muscle cells, increasing the rate of glucose uptake into these cells and stimulating the conversion of glucose to glycogen (glycogenesis) for storage. Both effects remove glucose from the blood, lowering blood glucose concentration back toward its normal set point; once glucose returns to normal, β cell stimulation (and insulin secretion) decreases — a negative feedback loop.

Bài tập luyện tập

Explain the roles of glycogenolysis and gluconeogenesis in raising blood glucose concentration during a period of fasting.

Lời giải chi tiết

Falling blood glucose is detected by α cells, which secrete glucagon. Glucagon stimulates the liver to break down stored glycogen back into glucose (glycogenolysis), releasing glucose directly into the blood. It also stimulates the liver to synthesise new glucose molecules from

non-carbohydrate sources such as amino acids and glycerol (gluconeogenesis), providing an additional source of glucose once glycogen stores start to run low. Together these raise blood glucose back toward the normal set point.

Bài tập luyện tập

A patient has fasting blood glucose that remains persistently very high, and blood tests show insulin is present at normal or even elevated concentrations. Which type of diabetes does this most likely indicate, and why?

(A) Type 1, because insulin is completely absent

(B) Type 2, because target cells have reduced sensitivity to insulin despite it being present

(C) Neither — this pattern is inconsistent with diabetes

(D) Type 1, because glucagon secretion has stopped

Lời giải chi tiết

Since insulin is present (even elevated) yet blood glucose remains high, the problem cannot be a lack of insulin (which would indicate Type 1); instead, target cells (liver/muscle) must have reduced sensitivity to insulin — insulin resistance/receptor downregulation — the hallmark of **Type 2** diabetes. **(B)**.

Bài tập luyện tập

Explain why Type 1 diabetes is usually treated with insulin injections, whereas Type 2 diabetes can often initially be managed by diet and exercise alone.

Lời giải chi tiết

In Type 1 diabetes, the β cells that produce insulin have been destroyed by an autoimmune attack, so essentially no insulin is produced — the missing hormone must be replaced directly by injection, since there is no functional tissue left to stimulate. In Type 2 diabetes, insulin is still produced (at least initially), but target cells respond poorly to it; reducing carbohydrate intake and increasing physical activity can improve insulin sensitivity and reduce the demand on the pancreas, which is often enough to control blood glucose without medication in early stages (though oral drugs or insulin may become necessary as the condition progresses).

Bài tập luyện tập

Using the blood glucose data in the worked example table (healthy, Type 1, Type 2), estimate how much higher the peak glucose concentration is in the untreated Type 1 individual compared with the healthy individual, and explain the physiological basis for this difference.

Lời giải chi tiết

Peak glucose in the healthy individual is 7.2 mmol dm^{-3} (at 60 min); peak glucose in the untreated Type 1 individual is about 17.5 mmol dm^{-3} (at 120 min) — a difference of roughly 10.3 mmol dm^{-3}. This is because the healthy individual secretes insulin in response to rising glucose, driving rapid cellular uptake and glycogenesis, while the Type 1 individual has no functional β cells and so cannot secrete insulin at all — glucose from the meal continues to

accumulate in the blood largely unchecked.

Bài tập luyện tập

Name the three structures/layers a molecule must cross during ultrafiltration to pass from the glomerular capillary into the Bowman's capsule, and state one substance normally excluded at this stage.

Lời giải chi tiết

The three layers are: (1) the fenestrated (pored) endothelium of the glomerular capillary, (2) the basement membrane (acting as a molecular sieve), and (3) the podocytes of the Bowman's capsule wall, with gaps (filtration slits) between their foot processes. Large plasma proteins (e.g. albumin) and blood cells are normally excluded, as they are too large to cross the basement membrane.

Bài tập luyện tập

Explain why the afferent arteriole of the glomerulus being wider than the efferent arteriole is essential for ultrafiltration to occur.

Lời giải chi tiết

Because blood enters the glomerulus through a wider vessel than the one it leaves through, blood cannot drain away from the capillary knot as quickly as it arrives, causing a build-up of high hydrostatic pressure within the glomerular capillaries. It is this elevated pressure that physically forces water and small solutes out across the capillary wall, basement membrane and podocytes into the Bowman's capsule; without this pressure difference, filtration would not occur.

Bài tập luyện tập

Explain, using the term co-transport, how essentially all the glucose in the glomerular filtrate is normally reabsorbed in the proximal convoluted tubule, even though glucose must move against its concentration gradient at one stage.

Lời giải chi tiết

A sodium-potassium pump on the basal membrane of PCT cells actively pumps Na^+ out of the cell into the blood, keeping intracellular Na^+ concentration low. This allows Na^+ to diffuse back into the cell down its concentration gradient through co-transporter proteins in the microvillus (apical) membrane; the energy released by this movement is used to simultaneously transport glucose into the cell against its own concentration gradient (secondary active transport). Glucose then diffuses out of the cell into the blood down its concentration gradient. This coupling of glucose movement to the Na^+ gradient is what allows glucose to be reabsorbed even when its concentration inside the cell exceeds that in the tubule fluid.

Bài tập luyện tập

Suggest why proximal convoluted tubule cells have (a) many microvilli and (b) many mitochondria.

Lời giải chi tiết

(a) Microvilli greatly increase the surface area of the apical membrane, increasing the number of co-transporter/channel proteins that can be present and so increasing the rate of reabsorption of glucose, amino acids and ions. (b) Reabsorption by co-transport depends on active transport of Na^+ by the sodium-potassium pump, which requires large amounts of ATP; many mitochondria allow a high rate of aerobic respiration to supply this ATP.

Bài tập luyện tập

Which statement correctly describes the permeability properties of the two limbs of the loop of Henle?

(A) Both limbs are permeable to water and impermeable to salt

(B) The descending limb is permeable to water but not salt; the ascending limb is impermeable to water but actively pumps out salt

(C) The descending limb actively pumps out salt; the ascending limb is permeable to water

(D) Neither limb is permeable to water or salt

Lời giải chi tiết

The descending limb allows water to leave by osmosis into the increasingly salty medulla but does not allow salt to cross; the ascending limb actively transports Na^+/Cl^- out into the medulla but is impermeable to water, so water cannot follow. **(B)**.

Bài tập luyện tập

Explain why the arrangement of the loop of Henle is described as a ”countercurrent multiplier,” and explain the functional consequence of the osmotic gradient it creates.

Lời giải chi tiết

Fluid flows in opposite directions in the descending and ascending limbs (countercurrent), and the ascending limb’s active salt pumping is reinforced repeatedly along the length of the loop because the two limbs lie side by side (the effect is ”multiplied” rather than acting only once). This builds up a steep osmotic gradient in the medulla, with solute concentration increasing from the cortex-medulla boundary down to the tip of the medulla. The functional consequence is that, when the collecting duct is made permeable to water by ADH, water can be drawn out of the collecting duct fluid by osmosis as it passes through this gradient, allowing urine to be concentrated well above the concentration of blood plasma.

Bài tập luyện tập

A desert mammal has a much longer loop of Henle (relative to kidney size) than a freshwater aquatic mammal. Explain the adaptive significance of this difference.

Lời giải chi tiết

A longer loop of Henle allows the countercurrent multiplier to act over a greater distance, building up a much steeper and deeper osmotic gradient in the medulla. This allows far more water to be reabsorbed from the collecting duct by osmosis, producing highly concentrated urine and minimising water loss — a critical adaptation for an animal living where water is

scarce. The aquatic mammal, with ready access to water, does not need to conserve water so strictly and can afford a shorter loop and more dilute urine.

Bài tập luyện tập

The GFR of a patient is measured at 150 dm^3/day, and it is found that 99.2% of the water in the filtrate is reabsorbed. Calculate the daily urine volume produced.

(A) 1.2 dm^3/day
(B) 12 dm^3/day
(C) 0.12 dm^3/day
(D) 3.0 dm^3/day

Lời giải chi tiết

$150 \times (1 - 0.992) = 150 \times 0.008 =$ **1.2** dm^3/day. **(A)**.

Bài tập luyện tập

State the location of osmoreceptors, and describe how they detect a fall in blood water potential.

Lời giải chi tiết

Osmoreceptors are located in the hypothalamus. When blood water potential falls (i.e. the blood becomes more concentrated in solutes), the osmoreceptor cells lose water by osmosis to their surroundings and shrink; this change in cell volume/shape is what stimulates the neurosecretory cells to release more ADH from the posterior pituitary.

Bài tập luyện tập

Describe, in the correct sequence, the effect of ADH on the collecting duct at the molecular level.

(A) ADH directly closes ion channels in the proximal tubule
(B) ADH binds receptors on collecting duct cells, causing vesicles containing aquaporin proteins to fuse with the apical membrane, increasing permeability to water
(C) ADH stimulates glycogenolysis in the collecting duct
(D) ADH increases the width of the afferent arteriole

Lời giải chi tiết

ADH binds to receptors on the surface of collecting duct cells; this triggers the insertion of aquaporin (water channel) proteins into the apical (luminal) membrane by vesicle fusion, increasing the permeability of the duct to water and so increasing water reabsorption. **(B)**.

Bài tập luyện tập

Explain why drinking a large volume of water quickly leads to a large volume of dilute urine within a short time.

Lời giải chi tiết

Drinking a large volume of water raises blood water potential; osmoreceptors in the hypothalamus are stimulated less, so less ADH is released from the posterior pituitary. With less ADH, fewer aquaporins are inserted into the collecting duct membrane, reducing its permeability to water. Less water is therefore reabsorbed from the collecting duct as it passes through the medulla, so a larger volume of more dilute urine is produced — restoring blood water potential toward normal by negative feedback.

Bài tập luyện tập

Explain why alcohol consumption can lead to dehydration despite the drinker having consumed a large volume of liquid.

Lời giải chi tiết

Alcohol directly inhibits the release of ADH from the posterior pituitary, regardless of the actual blood water potential. This reduces aquaporin insertion in the collecting duct and reduces water reabsorption, so more water than usual is lost in a larger volume of dilute urine — a diuretic effect. If this water loss exceeds the volume of liquid consumed (or is not adequately replaced), the net effect is dehydration.

Bài tập luyện tập

State the thermoregulatory centre in mammals, and describe two mechanisms of heat loss that it coordinates when core body temperature rises above normal.

Lời giải chi tiết

The thermoregulatory centre is the hypothalamus. When body temperature rises, it coordinates: (1) vasodilation of skin arterioles, increasing blood flow near the skin surface so more heat is lost to the surroundings by radiation/convection; (2) increased sweating, with evaporation of sweat from the skin removing latent heat and cooling the body. (Flattening of hair/fur, reducing the insulating air layer, is a further valid mechanism.)

Bài tập luyện tập

Explain why shivering increases body temperature, with reference to cellular respiration.

Lời giải chi tiết

Shivering is rapid, involuntary contraction of skeletal muscle. Muscle contraction requires ATP, which is generated by increased cellular respiration; because respiration is not perfectly efficient, a large proportion of the chemical energy released is lost as heat rather than being used for muscle work, and this heat warms the surrounding tissue and blood, raising body temperature.

Bài tập luyện tập

Explain why vasoconstriction of skin arterioles helps conserve body heat, and explain why this is described as a negative feedback response.

Lời giải chi tiết

Vasoconstriction narrows the arterioles supplying skin capillaries, reducing blood flow near the cool body surface; since less warm blood reaches the surface, less heat is lost to the environment by radiation and convection, helping the core stay warm. This is negative feedback because the response (reduced heat loss) is triggered by a fall in body temperature below the set point and acts to *correct* that fall (raising temperature back toward the set point), rather than pushing temperature further away from normal.

Bài tập luyện tập

A person exercises vigorously in hot weather. Describe and explain the combined homeostatic responses you would expect regarding (a) blood glucose and (b) body temperature.

Lời giải chi tiết

(a) Vigorous exercise increases glucose use by respiring muscle, so blood glucose tends to fall; this is detected by α cells, which secrete more glucagon, stimulating glycogenolysis and gluconeogenesis in the liver to release glucose into the blood and prevent it falling too low.
(b) Increased muscular activity generates heat as a by-product of increased respiration, and hot weather adds further heat; the hypothalamus detects the rise in blood/core temperature and triggers vasodilation of skin arterioles and increased sweating, both increasing heat loss (evaporative cooling from sweat is particularly important in hot conditions where radiating heat to the environment is less effective). Both responses illustrate negative feedback correcting deviations from the normal set points for glucose concentration and body temperature respectively.

Bài tập luyện tập

Explain why a person with Type 1 diabetes who has taken too much insulin (relative to their food intake) may experience symptoms of low blood glucose (hypoglycaemia), and explain what physiological response would normally help correct this in a non-diabetic person.

Lời giải chi tiết

Excess injected insulin drives glucose uptake into liver/muscle cells and glycogenesis at a rate that is too high relative to the glucose available from the diet, so blood glucose falls below normal (hypoglycaemia), which can cause symptoms such as shakiness, confusion and weakness (the brain is highly dependent on a steady glucose supply). In a non-diabetic person, falling blood glucose would normally be detected by α cells, which would secrete more glucagon, stimulating glycogenolysis and gluconeogenesis in the liver to release glucose and restore blood glucose to normal — but a person with Type 1 diabetes who has injected insulin cannot easily reverse the effect of that insulin through their own glucagon response alone, since the amount and timing of injected insulin is not under the body's own negative feedback control.

11.3.2 Part B: Control and Coordination

Bài tập luyện tập

Distinguish between the central nervous system (CNS) and the peripheral nervous system (PNS), and state the roles of sensory and motor neurones within a reflex arc.

Lời giải chi tiết

The CNS (brain and spinal cord) is where information is processed and coordinated; the PNS consists of all the nerves connecting the CNS to receptors and effectors elsewhere in the body. In a reflex arc, sensory neurones carry impulses from a receptor toward the CNS (specifically to a relay neurone in the spinal cord), and motor neurones carry impulses from the CNS out to an effector (muscle or gland) to bring about a response.

Bài tập luyện tập

Write out, in the correct order, the full sequence of structures involved in a spinal reflex arc, from stimulus to response.

Lời giải chi tiết

Stimulus → receptor → sensory neurone → relay neurone (in the spinal cord) → motor neurone → effector → response.

Bài tập luyện tập

Explain why the speed and involuntary nature of reflex responses are important for survival.

Lời giải chi tiết

Because a reflex pathway is short (often only a few synapses) and does not require conscious processing in the brain, the response can occur extremely quickly — often within milliseconds of the stimulus. This speed is essential for protection: for example, withdrawing a hand from a painful/hot stimulus before conscious awareness of pain even develops minimizes tissue damage. If the response instead had to be consciously decided upon each time, the extra processing time could result in significant, avoidable injury.

Bài tập luyện tập

Explain the role of Schwann cells in a myelinated neurone, and explain how they contribute to saltatory conduction.

Lời giải chi tiết

Schwann cells wrap tightly around the axon in a spiral, forming the myelin sheath, which electrically insulates the axon membrane. Gaps between adjacent Schwann cells (nodes of Ranvier) are the only points where the axon membrane is exposed to the extracellular fluid and where ion channels are concentrated. Because the insulated regions cannot depolarise, the action potential can only be regenerated at successive nodes of Ranvier — the impulse effectively "jumps" from node to node (saltatory conduction), which is much faster than continuous depolarisation of every part of the membrane, as occurs in an unmyelinated axon.

Bài tập luyện tập

Explain how the sodium-potassium pump and K^+ leak channels together maintain the resting potential of a neurone at about -70 mV.

Lời giải chi tiết

The sodium-potassium pump actively transports $3\,Na^+$ ions out of the axon for every $2\,K^+$ ions pumped in, using ATP; this creates concentration gradients with more Na^+ outside and more K^+ inside the axon. Because the membrane has more open K^+ leak channels than Na^+ channels, K^+ diffuses back out of the axon down its concentration gradient more readily than Na^+ can diffuse in, leaving the inside of the membrane with a net negative charge relative to the outside (further reinforced by negatively charged intracellular proteins that cannot cross the membrane) — together maintaining a stable resting potential of about -70 mV.

Bài tập luyện tập

Which of the following correctly describes the events of depolarisation during an action potential?

(A) Voltage-gated K^+ channels open, K^+ leaves the axon, the membrane potential falls

(B) Voltage-gated Na^+ channels open, Na^+ enters the axon down its electrochemical gradient, the membrane potential rises toward positive values

(C) The sodium-potassium pump actively pumps Na^+ into the axon

(D) Ca^{2+} enters the axon, directly causing depolarisation of the axon membrane

Lời giải chi tiết

Depolarisation results from voltage-gated Na^+ channels opening in response to the membrane reaching threshold, allowing Na^+ to rush down its steep electrochemical gradient into the axon and making the inside of the membrane progressively more positive. **(B)**.

Bài tập luyện tập

Describe the sequence of channel events responsible for repolarisation following the peak of an action potential.

Lời giải chi tiết

At the peak of the action potential, voltage-gated Na^+ channels close and become inactivated (unable to reopen immediately), stopping further Na^+ influx. At around the same time, voltage-gated K^+ channels (which open more slowly than Na^+ channels) open fully, allowing K^+ to diffuse out of the axon down its concentration gradient. The loss of positive charge from the inside of the membrane makes the membrane potential fall back toward (and briefly below) the resting value — repolarisation.

Bài tập luyện tập

Explain why hyperpolarisation (the "undershoot") occurs immediately after repolarisation.

(A) Because Na^+ channels reopen too early

(B) Because voltage-gated K^+ channels remain open slightly longer than needed, so slightly too much K^+ leaves the axon before the channels close

(C) Because the sodium-potassium pump reverses direction

(D) Because Ca^{2+} enters the axon at this stage

Lời giải chi tiết

Voltage-gated K^+ channels close relatively slowly, so they remain open a little longer than is needed to just reach the resting potential; the resulting slight excess efflux of K^+ makes the membrane potential transiently more negative than the normal resting value, before the sodium-potassium pump and closure of the remaining K^+ channels restore the resting potential. **(B)**.

Bài tập luyện tập

Explain two distinct functional consequences of the refractory period for the propagation and frequency of nerve impulses.

Lời giải chi tiết

(1) **Unidirectional propagation:** because the region of membrane that has just fired an action potential is refractory (its Na^+ channels are inactivated), it cannot be re-stimulated immediately; only the region ahead (still at resting potential and excitable) can be depolarised next, so the impulse can only travel forward, never backward, along the axon. (2) **Maximum firing frequency:** since a new action potential cannot be triggered until the refractory period of the previous one has ended, the length of the refractory period sets an absolute upper limit on how many action potentials per second (frequency) a given axon can produce, regardless of how intense the stimulus is.

Bài tập luyện tập

Explain what is meant by the ”all-or-nothing” principle of action potentials, and explain how the nervous system nonetheless encodes the intensity of a stimulus.

Lời giải chi tiết

The all-or-nothing principle states that once a stimulus is strong enough to depolarise the membrane to threshold, a full-sized action potential is always produced (with the same peak amplitude, regardless of how far above threshold the stimulus was); stimuli below threshold produce no action potential at all. Because the size of individual action potentials cannot vary, stimulus intensity is instead encoded by the **frequency** of action potentials generated (a stronger stimulus produces more impulses per second) and by the number of sensory neurones recruited/activated.

Bài tập luyện tập

An axon’s absolute refractory period lasts 2.5 ms. Calculate the maximum possible firing frequency of this axon.

(A) 40 Hz
(B) 400 Hz
(C) 4000 Hz
(D) 250 Hz

Lời giải chi tiết

$f_{\text{max}} = \dfrac{1}{2.5 \times 10^{-3}\ \text{s}} =$ **400** Hz. **(B)**.

Bài tập luyện tập

A signal must travel 2.4 m along a myelinated axon conducting at 120 m s^{-1}. Calculate the time taken, and compare it with an unmyelinated axon of the same length conducting at 4 m s^{-1}.

Lời giải chi tiết

Myelinated: $t = \dfrac{2.4}{120} = 0.02$ s $= 20$ ms. Unmyelinated: $t = \dfrac{2.4}{4} = 0.6$ s $= 600$ ms. The myelinated axon is 30 times faster, illustrating the benefit of saltatory conduction for pathways where speed is critical (e.g. reflexes).

Bài tập luyện tập

A membrane potential recording shows: -70 mV at $t = 0$ ms, $+38$ mV at $t = 1.4$ ms, -50 mV at $t = 2.0$ ms, -85 mV at $t = 2.6$ ms, -70 mV at $t = 4.0$ ms. Identify the phase of the action potential occurring closest to each time given.

Lời giải chi tiết

$t = 0$ ms (-70 mV): resting potential. $t = 1.4$ ms ($+38$ mV, near the peak): depolarisation almost complete (most voltage-gated Na^+ channels open). $t = 2.0$ ms (-50 mV, falling from the peak): repolarisation (Na^+ channels inactivating, K^+ channels open, K^+ leaving the axon). $t = 2.6$ ms (-85 mV, below resting): hyperpolarisation (undershoot) — part of the refractory period. $t = 4.0$ ms (-70 mV): resting potential restored, membrane excitable again.

Bài tập luyện tập

Explain the role of Ca^{2+} ions in synaptic transmission, including what triggers their entry into the presynaptic knob.

Lời giải chi tiết

When an action potential arrives at the presynaptic knob, it depolarises the presynaptic membrane, causing voltage-gated Ca^{2+} channels to open. Ca^{2+} then diffuses into the presynaptic knob down its steep electrochemical gradient. This influx of Ca^{2+} is the trigger that causes synaptic vesicles containing neurotransmitter to move toward and fuse with the presynaptic membrane, releasing their contents into the synaptic cleft by exocytosis. Without Ca^{2+} influx, neurotransmitter release (and therefore synaptic transmission) cannot occur.

Bài tập luyện tập

Explain the function of acetylcholinesterase at a cholinergic synapse, and explain what would happen to postsynaptic transmission if this enzyme were inhibited by a toxin.

Lời giải chi tiết

Acetylcholinesterase is an enzyme located in the synaptic cleft (and on the postsynaptic membrane) that hydrolyses acetylcholine into choline and ethanoic acid, rapidly removing it from the cleft once it has triggered a response. This prevents the postsynaptic membrane from being continuously stimulated by the same batch of neurotransmitter, allowing the synapse to reset and respond to new, discrete impulses. If acetylcholinesterase were inhibited, acetylcholine would remain in the cleft and continue binding receptors, causing prolonged, uncontrolled stimulation of the postsynaptic membrane (in a real organism this can cause continuous muscle contraction/paralysis, since the effector cannot ”reset” between impulses).

Bài tập luyện tập

Distinguish between an excitatory postsynaptic potential (EPSP) and an inhibitory postsynaptic potential (IPSP), and explain how each affects the likelihood of a postsynaptic action potential.

Lời giải chi tiết

An EPSP is a (usually small) depolarisation of the postsynaptic membrane, caused by ligand-gated channels opening to let in positive ions (e.g. Na^+); it brings the membrane potential closer to threshold, making a postsynaptic action potential *more* likely. An IPSP is a hyperpolarisation of the postsynaptic membrane (e.g. caused by opening Cl^- channels), moving the membrane potential further from threshold and making a postsynaptic action potential *less* likely. Whether an action potential is triggered depends on the combined, summed effect of all the EPSPs and IPSPs arriving at the postsynaptic membrane at a given moment.

Bài tập luyện tập

Distinguish between temporal and spatial summation at a synapse, using an example of each.

Lời giải chi tiết

Temporal summation occurs when a single presynaptic neurone fires several action potentials in rapid succession; the resulting EPSPs add together at the postsynaptic membrane before the first has fully decayed, potentially reaching threshold (e.g. a sensory neurone firing repeatedly in response to a sustained, intense stimulus). Spatial summation occurs when several different presynaptic neurones, all synapsing onto the same postsynaptic cell, fire at approximately the same time; their individual EPSPs combine at the postsynaptic membrane, potentially reaching threshold even though no single input alone would be sufficient (e.g. several sensory neurones responding to the same stimulus simultaneously).

Bài tập luyện tập

A postsynaptic neurone has a threshold of 15 mV depolarisation from resting potential. Each single presynaptic impulse from neurone X produces an EPSP of 4 mV, which decays fully before the next impulse (no summation possible from X alone in this scenario since impulses

are widely spaced). Neurone Y, synapsing on the same cell, also produces 4 mV EPSPs. If X and Y both fire simultaneously along with a third neurone Z (also 4 mV, same synapse target), will a postsynaptic action potential be triggered? Explain.

Lời giải chi tiết

If X, Y and Z all fire together, their EPSPs summate spatially (three separate presynaptic neurones acting on the same postsynaptic cell at the same time): $4 + 4 + 4 = 12$ mV combined depolarisation. Since 12 mV is less than the 15 mV threshold, this alone is **not** sufficient to trigger a postsynaptic action potential — a fourth simultaneous input (or additional summation) would be required to reach the 15 mV threshold.

Bài tập luyện tập

Which feature distinguishes hormonal communication from nervous communication in terms of how widely a signal is distributed in the body?

(A) Hormonal signals travel only along a single dedicated pathway to one effector

(B) Hormonal signals are carried in the blood and can potentially reach any cell in the body with matching receptors

(C) Nervous signals are distributed to every cell in the body simultaneously

(D) There is no difference in distribution between the two systems

Lời giải chi tiết

Hormones are secreted into the blood and circulate throughout the body, so they can potentially act on any cell that has the appropriate receptor, giving a widespread effect; nervous signals, by contrast, travel along specific neurone pathways to a precise target effector. **(B)**.

Bài tập luyện tập

Explain why hormonal responses tend to be slower to begin but longer-lasting than nervous responses.

Lời giải chi tiết

Hormonal responses depend on a chemical messenger being secreted into the blood, diffusing/being carried by the circulation to target cells, and then binding to receptors before an effect begins — this whole process takes longer than the rapid, direct electrical transmission of a nervous impulse along a neurone. Once released, however, a hormone typically remains active in the blood and continues to influence target cells for a longer period (until it is broken down or removed), whereas a nervous impulse's effect at a synapse (e.g. an EPSP) is very brief because neurotransmitter is rapidly removed/broken down. This combination of properties makes hormonal communication better suited to slower, longer-term processes (e.g. growth, metabolism, blood glucose regulation) while nervous communication suits rapid, short-lived responses (e.g. reflexes).

Bài tập luyện tập

Explain, in terms of auxin distribution, why a shoot grown with light shining from only one side bends toward the light.

Lời giải chi tiết

Under unilateral light, auxin produced at the shoot tip is transported laterally toward the shaded side of the shoot rather than diffusing straight down evenly (Cholodny–Went model). The shaded side therefore has a higher auxin concentration than the illuminated side. Since auxin stimulates cell elongation in shoot tissue, cells on the shaded side elongate more than cells on the illuminated side, and this unequal elongation causes the shoot to curve, bending the tip toward the light source.

Bài tập luyện tập

Explain why the same lateral redistribution of auxin toward the lower side of a root, under the influence of gravity, causes the root to grow *downward* rather than curving upward.

(A) Because roots do not respond to auxin at all

(B) Because root cells are far more sensitive to auxin than shoot cells, so the same higher auxin concentration inhibits (rather than promotes) elongation on the lower side, causing the upper side to elongate more and the root to curve downward

(C) Because auxin is not present in roots

(D) Because gravity directly bends the root without any hormone involved

Lời giải chi tiết

Root cells are much more sensitive to auxin than shoot cells. The higher auxin concentration that accumulates on the lower side (under gravity) actually inhibits cell elongation there, rather than promoting it as it would in a shoot. Since the lower side elongates less and the upper side (with less auxin) elongates more, the root curves downward, toward gravity — positive gravitropism. **(B)**.

Bài tập luyện tập

In a classic experiment, a coleoptile tip is removed and placed back centrally on an agar block sitting on the decapitated stump, and the plant is then exposed to unilateral light. Growth resumes and the coleoptile bends toward the light almost as if the tip had never been removed. What does this result demonstrate?

Lời giải chi tiết

Since a tip that has been physically detached and then simply placed back (on an intervening agar block, which itself has no cells) can still restore both growth and normal directional bending, the essential signal for phototropism must be a **diffusible chemical** (auxin) that can pass through the agar and is produced by the tip tissue, rather than depending on any permanent physical/structural connection of the tip to the rest of the shoot.

Bài tập luyện tập

A researcher inserts a thin, impermeable mica sheet vertically all the way through the tip of a coleoptile (splitting the tip into two halves that cannot exchange auxin sideways, though auxin can still move straight down within each half). Under unilateral light, the coleoptile grows straight upward instead of bending toward the light. Explain this result.

Lời giải chi tiết

Because the mica barrier prevents auxin moving *laterally* across the tip (from the illuminated side to the shaded side), unilateral light can no longer cause the normal lateral redistribution of auxin toward the shaded side, even though auxin can still be transported downward within each half independently. Since both halves therefore receive roughly equal (undistributed) amounts of auxin and elongate at similar rates, the coleoptile grows straight rather than bending — confirming that it is the *lateral redistribution* of auxin (not a change in the total amount produced) that causes light-induced bending.

Bài tập luyện tập

A decapitated coleoptile has an agar block (which has absorbed auxin from an isolated tip) placed asymmetrically on the *right*-hand side of the cut stump, in complete darkness. Predict the direction of any resulting curvature and explain your reasoning.

Lời giải chi tiết

Auxin diffuses from the agar block into the cells directly beneath it, so the right-hand side of the stump receives a much higher auxin concentration than the left-hand side. Since auxin promotes cell elongation in shoot tissue, cells on the right elongate faster than those on the left. This unequal elongation causes the coleoptile to curve toward the side that elongated *less* — that is, the coleoptile bends to the **left** (away from the side where the agar block was placed), even though no light was present, demonstrating that unequal auxin distribution alone is sufficient to cause curvature.

Inheritance

A2 Level

Mục tiêu Unit: Giảm phân và các nguồn biến dị tổ hợp (trao đổi chéo, phân li độc lập, thụ tinh ngẫu nhiên); thuật ngữ di truyền cơ bản; lai một tính trạng và hai tính trạng; tương tác gen (đồng trội, đa allele, epistasis); di truyền liên kết giới tính; liên kết gen trên cùng NST thường và tần số tái tổ hợp; kiểm định χ^2; nguyên lý cân bằng Hardy–Weinberg.

12.1 Meiosis and genetic variation

Meiosis is a type of nuclear division that produces four **haploid** daughter cells (gametes) from one diploid parent cell, each genetically different from the others and from the parent cell. It consists of two successive divisions, **meiosis I** and **meiosis II**, following a single round of DNA replication.

In **prophase I**, homologous chromosomes (one maternal, one paternal copy of each chromosome, carrying the same genes at the same loci but not necessarily the same alleles) pair up along their length in a process called **synapsis**, forming a structure called a **bivalent** (each bivalent consists of four chromatids — two from each homologue). At points called **chiasmata**, non-sister chromatids of the two homologous chromosomes break and rejoin, exchanging equivalent sections of DNA — **crossing over**. This creates chromatids with new combinations of alleles that did not exist together on either original chromosome. In **metaphase I**, bivalents line up along the equator of the cell; for each bivalent, which homologue faces which pole is random and independent of how every other bivalent is orientated — **independent assortment**. In **anaphase I**, whole homologous chromosomes (each still made of two sister chromatids joined at the centromere) separate and move to opposite poles. After telophase I and cytokinesis, two haploid cells are formed, each containing one chromosome (of sister chromatids) from each original homologous pair.

Meiosis II then proceeds much like mitosis in each of these two haploid cells: in anaphase II, the sister chromatids of each chromosome separate and move to opposite poles. The overall result of meiosis I followed by meiosis II is four haploid cells, each genetically distinct.

Sources of genetic variation

Meiosis (together with fertilisation) generates variation in three ways: (1) **crossing over** in prophase I creates new combinations of alleles *within* a chromosome that were not present on either parental chromosome; (2) **independent assortment** of homologous pairs at metaphase I means each gamete receives a random mixture of maternal and paternal chromosomes — for an organism with n homologous pairs, there are 2^n possible chromosome combinations in a gamete from independent assortment alone; (3) **random fertilisation** means any one of a huge number of possible male gametes can fuse with any one of a huge number of possible female gametes, multiplying the variation still further.

Worked example: how many gamete combinations?

Humans have $n = 23$ pairs of homologous chromosomes. *(a)* Calculate the number of genetically distinct chromosome combinations possible in a single gamete from independent assortment alone (ignoring crossing over). *(b)* Estimate the number of possible genetically distinct zygotes from random fertilisation of any such egg by any such sperm.

(a) Number of combinations $= 2^n = 2^{23} =$ **8 388 608** (over 8 million) possible chromosome combinations in a single gamete.

(b) Since any of these 2^{23} possible eggs could in principle fuse with any of 2^{23} possible sperm, the number of possible zygote combinations is

$$2^{23} \times 2^{23} = 2^{46} \approx \mathbf{7.0 \times 10^{13}} \text{ (about 70 trillion),}$$

and this is *before* taking into account the additional variation introduced by crossing over in each parent — illustrating why (barring identical twins) no two offspring of the same parents are genetically identical.

Mitosis produces two genetically **identical** diploid daughter cells (growth, repair, asexual reproduction) and involves no pairing of homologous chromosomes and no crossing over. **Meiosis** produces four genetically **different** haploid daughter cells (gametes, for sexual reproduction), introducing variation via crossing over (prophase I) and independent assortment (metaphase I); this variation is further increased at fertilisation by the random fusion of gametes.

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Giảm phân (meiosis) tạo ra 4 tế bào **đơn bội** khác nhau về mặt di truyền từ 1 tế bào lưỡng bội, qua 2 lần phân chia (giảm phân I và II) sau 1 lần nhân đôi DNA. Ở kỳ đầu I, các NST tương đồng bắt cặp tạo **cặp tương đồng (bivalent)**; tại các điểm **chiasma**, các nhiễm sắc tử không chị em trao đổi đoạn DNA — đây là **trao đổi chéo (crossing over)**, tạo tổ hợp allele mới. Ở kỳ giữa I, các cặp tương đồng sắp xếp ngẫu nhiên, độc lập với nhau — đây là **phân li độc lập (independent assortment)**. Giảm phân II tương tự nguyên phân, tách các nhiễm sắc tử chị em. Ba nguồn biến dị: trao đổi chéo, phân li độc lập, và **thụ tinh ngẫu nhiên**.

12.2 Genetic terminology and monohybrid inheritance

Before working with genetic crosses, several terms must be defined precisely. A **gene** is a sequence of DNA (nucleotides) that codes for a specific polypeptide/protein, or more generally a heritable unit controlling a particular characteristic, occupying a specific position (its **locus**) on a chromosome. An **allele** is one of the possible alternative versions of a gene, differing from other alleles of the same gene in its base sequence. The **genotype** of an organism is its allele composition for the gene(s) in question; its **phenotype** is its observable characteristics, resulting from the interaction of genotype and environment. An organism is **homozygous** at a locus if it carries two identical alleles there, and **heterozygous** if it carries two different alleles. An allele is **dominant** if it is expressed in the phenotype whenever it is present (masking a recessive allele in a heterozygote); an allele is **recessive** if it is only expressed in the phenotype when present in the homozygous state (i.e. it is masked by a dominant allele in a heterozygote). Alleles are **codominant** if, in a heterozygote, both are expressed simultaneously and distinctly, with neither masking the other.

A **monohybrid cross** follows the inheritance of a single gene. Consider pea plant height, where allele T (tall) is dominant to allele t (dwarf). Crossing two heterozygous (Tt) plants:

	T	t
T	TT	Tt
t	Tt	tt

Figure 1. Monohybrid cross Tt × Tt. Genotype ratio 1 TT : 2 Tt : 1 tt; phenotype ratio 3 tall : 1 dwarf.

Each parent produces gametes carrying either T or t (in equal proportion), and the Punnett square shows all four equally likely combinations at fertilisation: 1 TT (tall) : 2 Tt (tall) : 1 tt (dwarf) by genotype, giving a phenotype ratio of 3 tall : 1 dwarf.

A **test cross** is used to determine whether an individual showing the dominant phenotype is homozygous (TT) or heterozygous (Tt): the unknown individual is crossed with a homozygous recessive individual (tt). If *all* offspring show the dominant phenotype, the unknown parent was most likely TT; if approximately **half** the offspring show the dominant phenotype and half the recessive phenotype (a 1:1 ratio), the unknown parent was heterozygous (Tt).

Worked example: monohybrid cross and test cross

In pea plants, tall (T) is dominant to dwarf (t). A tall plant of unknown genotype is crossed with a dwarf plant (tt); of 80 offspring, 38 are tall and 42 are dwarf. *(a)* Deduce the genotype of the originally tall parent. *(b)* State the expected genotype and phenotype ratio.

(a) The offspring are close to a 1:1 ratio of tall : dwarf ($38{:}42 \approx 1{:}1$, not all-tall), which is the expected outcome of a test cross Tt × tt. If the unknown parent had instead been TT, all offspring would be tall (Tt). Since roughly half the offspring are dwarf, the original tall parent must have been **heterozygous (Tt)**.

(b) Tt (gametes T, t) × tt (gametes t, t) gives offspring Tt (tall) and tt (dwarf) in a 1:1 genotype and phenotype ratio, consistent with the observed data.

12.3 Dihybrid inheritance

A **dihybrid cross** follows the inheritance of two genes simultaneously. If the two genes are located on *different* (non-homologous) chromosomes, they assort independently of each other during meiosis (metaphase I), so the alleles of one gene are inherited independently of the alleles of the other.

Consider pea seed shape (allele R, round, dominant to r, wrinkled) and seed colour (allele Y, yellow, dominant to y, green), on different chromosomes. Crossing two double heterozygotes (RrYy × RrYy): each parent produces four types of gamete in equal proportion — RY, Ry, rY, ry — giving a $4 \times 4 = 16$-box Punnett square.

	RY	Ry	rY	ry
RY	RRYY	RRYy	RrYY	RrYy
Ry	RRYy	RRyy	RrYy	Rryy
rY	RrYY	RrYy	rrYY	rrYy
ry	RrYy	Rryy	rrYy	rryy

Figure 2. Dihybrid cross RrYy × RrYy (independent genes). Phenotype ratio 9 round yellow : 3 round green : 3 wrinkled yellow : 1 wrinkled green.

Reading off the 16 boxes: 9 boxes show at least one R and one Y allele (round, yellow); 3 boxes show at least one R but only y alleles (round, green); 3 boxes show only r alleles but at least one Y (wrinkled, yellow); 1 box is rryy (wrinkled, green) — the classic 9:3:3:1 phenotype ratio that results whenever two genes on different chromosomes are each heterozygous and assort independently.

Worked example: dihybrid cross

In pea plants, round seeds (R) are dominant to wrinkled (r), and yellow seeds (Y) are dominant to green (y); the two genes are on different chromosomes. A plant heterozygous for both genes (RrYy) is self-pollinated (RrYy $\times$ RrYy) to give 320 offspring. Calculate the expected number of offspring in each of the four phenotype classes.

The expected ratio is $9{:}3{:}3{:}1$ (total 16 parts) for 320 offspring, so each "part" $= 320/16 = 20$.

Phenotype	Ratio	Expected number
Round, yellow	9	$9 \times 20 = 180$
Round, green	3	$3 \times 20 = 60$
Wrinkled, yellow	3	$3 \times 20 = 60$
Wrinkled, green	1	$1 \times 20 = 20$

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Lai một tính trạng (monohybrid, Tt $\times$ Tt) cho tỉ lệ kiểu gen $1{:}2{:}1$ và kiểu hình $3{:}1$. Lai hai tính trạng (dihybrid, hai gen nằm trên hai NST khác nhau, phân li độc lập, RrYy $\times$ RrYy) cho tỉ lệ kiểu hình kinh điển $9{:}3{:}3{:}1$. Phép lai phân tích (test cross, lai với cá thể đồng hợp lặn) dùng để xác định kiểu gen của cá thể mang kiểu hình trội chưa rõ kiểu gen — nếu đời con phân li $1{:}1$, cá thể ban đầu là dị hợp tử.

12.4 Gene interactions: codominance, multiple alleles and epistasis

Not every gene shows simple dominant/recessive inheritance, and not every pair of genes produces a $9{:}3{:}3{:}1$ ratio.

Codominance occurs when both alleles in a heterozygote are expressed simultaneously and distinctly, with neither masking the other. A classic example is the roan coat colour in cattle: allele C^R produces red hairs and allele C^W produces white hairs; a heterozygote C^RC^W has a coat of *both* red and white hairs mixed together ("roan") — the alleles are not blended within a single hair, but both are visibly expressed in the overall phenotype.

Worked example: codominance in cattle coat colour

Roan cattle are heterozygous C^RC^W (a mix of red and white hairs); red cattle are C^RC^R; white cattle are C^WC^W. Two roan cattle are crossed ($C^RC^W \times C^RC^W$). Predict the genotype and phenotype ratio of the offspring.

Each parent produces gametes C^R or C^W in equal proportion. The Punnett square gives: $1\,C^RC^R$ (red) : $2\,C^RC^W$ (roan) : $1\,C^WC^W$ (white). Because C^R and C^W are codominant, each genotype corresponds to a visually distinct phenotype, so the phenotype ratio matches the genotype ratio exactly: **1** red : **2** roan : **1** white.

Multiple alleles occur when a gene has more than two alleles present within a population (though any individual still carries only two). The human **ABO blood group** system is controlled by a single gene with three alleles: I^A and I^B are codominant with each other, and both are dominant to i (which is recessive to both).

Genotype	Phenotype (blood group)
I^AI^A or I^Ai	A
I^BI^B or I^Bi	B
I^AI^B	AB
ii	O

Table 1. Genotype–phenotype relationships for the ABO blood group system.

Worked example: ABO blood group parentage

Can a blood-group-AB father and a blood-group-O mother have a blood-group-O child? Justify your answer using genotypes.

The father, blood group AB, has genotype I^AI^B; since he carries no i allele, his gametes can only be I^A or I^B — he can never contribute an i allele to a child. The mother, blood group O, has genotype ii, so all her gametes carry i. Every child therefore receives i from the mother and either I^A or I^B from the father, giving genotype I^Ai (blood group A) or I^Bi (blood group B), each with probability $\frac{1}{2}$. **No, this couple cannot have a blood-group-O (or AB) child** — every child must be either group A or group B.

Worked example: predicting ABO offspring proportions

A heterozygous blood-group-A mother (I^Ai) and a heterozygous blood-group-B father (I^Bi) have children. Predict the proportion of children expected in each ABO blood group.

Mother's gametes: I^A or i (each $\frac{1}{2}$). Father's gametes: I^B or i (each $\frac{1}{2}$). Combining at fertilisation: I^AI^B (AB), I^Ai (A), I^Bi (B), ii (O), each combination with probability $\frac{1}{4}$. All **four** blood groups (A, B, AB, O) are expected, each in **25**% of children.

Epistasis occurs when the alleles of one gene mask or modify the phenotypic expression of a different gene, altering the ratio expected from simple independent assortment (e.g. changing $9{:}3{:}3{:}1$ into some other whole-number ratio that still sums to 16). A widely used example is coat colour in Labrador retrievers, controlled by two genes: gene B (allele B, black pigment, dominant to b, brown/chocolate pigment) determines *which* pigment is produced, while gene E (allele E, allows pigment to be deposited in the coat, dominant to e; the recessive homozygote ee blocks deposition of *any* pigment) determines *whether* the pigment (whichever type is present) is deposited at all.

Worked example: recessive epistasis

Two Labradors, both black and both heterozygous at both loci (BbEe $\times$ BbEe), are crossed. Using the standard dihybrid Punnett square (16 combinations), derive the phenotype ratio of the offspring, given that ee is epistatic to the B gene (any ee dog is yellow regardless of its B/b genotype).

The standard dihybrid categories (from a $9{:}3{:}3{:}1$-style Punnett square) are:

- $B\_E\_$ = $9/16$: black pigment produced *and* deposited → **black**.
- $bbE\_$ = $3/16$: brown pigment produced *and* deposited → **chocolate (brown)**.
- B_ee = $3/16$: black pigment would be produced, but ee blocks deposition → **yellow**.
- $bbee$ = $1/16$: brown pigment would be produced, but ee blocks deposition → **yellow**.

Since both ee classes ($3/16 + 1/16 = 4/16$) appear yellow regardless of the B gene, the phenotype ratio collapses from $9{:}3{:}3{:}1$ to

9 black : **3** chocolate : **4** yellow.

(!) Lỗi thường gặp: Epistasis không làm mất đi số tổ hợp kiểu gen (vẫn có đủ 16 tổ hợp trong ô Punnett), mà chỉ làm **gộp một số nhóm kiểu hình lại với nhau** vì một gen che lấp biểu hiện của gen kia. Luôn cộng lại đúng các phần trước khi kết luận tỉ lệ mới (ví dụ $3+1=4$ ở trên) — đừng vội giả định tỉ lệ luôn là $9{:}3{:}4$; mỗi kiểu tương tác gen (át chế trội, át chế lặn, bổ trợ...) cho một tỉ lệ biến thể khác nhau và cần suy luận lại từ bảng Punnett.

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Đồng trội (codominance): cả hai allele cùng biểu hiện rõ ràng ở thể dị hợp (ví dụ bò roan: đỏ + trắng). **Đa allele (multiple alleles)**: một gen có nhiều hơn 2 allele trong quần thể (ví dụ hệ nhóm máu ABO với I^A, I^B, i; I^A, I^B đồng trội, đều trội so với i). **Tương tác gen/át chế (epistasis)**: một gen che lấp hoặc làm thay đổi biểu hiện của gen khác, làm lệch tỉ lệ dihybrid chuẩn $9{:}3{:}3{:}1$ (ví dụ thành $9{:}3{:}4$ ở màu lông chó Labrador, khi kiểu gen ee chặn hoàn toàn sự lắng đọng sắc tố).

12.5 Sex determination and sex linkage

In mammals, sex is determined by a pair of **sex chromosomes**: females are XX (homogametic) and males are XY (heterogametic). The Y chromosome is much shorter than the X and carries far fewer genes, so genes located on the X chromosome but with no equivalent locus on the Y show a distinctive inheritance pattern called **sex linkage**: because males have only one copy of most X-linked genes, they are **hemizygous** for them and will show the phenotype of whatever single allele they carry, even if it is normally recessive; females, with two X chromosomes, can be homozygous or heterozygous (and heterozygous females are unaffected **carriers** if the allele is recessive).

Red-green colour blindness and haemophilia (a blood-clotting disorder) are both caused by recessive alleles on the X chromosome. Using haemophilia as an example, let X^H represent the normal (dominant) allele and X^h the haemophilia (recessive) allele.

Worked example: sex-linked pedigree cross

A woman who is an unaffected carrier for haemophilia (X^HX^h) has children with a man who does not have haemophilia (X^HY). Construct the cross and state the expected proportion of affected children, distinguishing sons and daughters.

Mother's gametes: X^H or X^h (each $\frac{1}{2}$). Father's gametes: X^H or Y (each $\frac{1}{2}$).

	X^H (from mother)	**X^h (from mother)**
X^H (from father)	X^HX^H (daughter, unaffected)	X^HX^h (daughter, carrier, unaffected)
Y (from father)	X^HY (son, unaffected)	X^hY (son, **affected**)

Overall, $\frac{1}{4}$ of *all* children are expected to be affected — specifically, **0**% of daughters are affected (though $\frac{1}{2}$ of daughters are unaffected carriers), while **50**% of sons are affected. This illustrates the classic sex-linked pattern: the condition "skips" the carrier mother's own phenotype but reappears in roughly half of her sons, while daughters are never affected from this particular cross (though they may pass the allele on to the next generation).

Sex-linked recessive conditions (e.g. red-green colour blindness, haemophilia) are much more common in **males** than females, because a male need inherit only *one* copy of the recessive allele (he is hemizygous) to be affected, whereas a female must inherit *two* copies (one from each parent) to be affected — an affected father cannot pass the condition directly to his sons (they receive his Y chromosome, not his X), but all his daughters will receive his affected X and become at least carriers.

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Ở động vật có vú, giới tính được xác định bởi cặp NST giới tính: nữ XX, nam XY. Gen **liên kết giới tính** nằm trên NST X biểu hiện khác nhau ở hai giới vì nam chỉ có **1** bản sao (thể dị hợp tử đơn - hemizygous) nên luôn biểu hiện allele đó dù là lặn, còn nữ có 2 bản sao nên có thể là người **mang gen lặn (carrier)** không biểu hiện bệnh. Ví dụ mù màu đỏ-lục và bệnh máu khó đông (haemophilia) đều liên kết X lặn — mẹ mang gen (dị hợp) có 50% con trai bị bệnh, con gái không bao giờ bị bệnh (nhưng có thể là người mang gen) nếu bố không bị bệnh.

12.6 Autosomal linkage and recombination

Genes located on the *same* autosome (non-sex chromosome) do not assort independently, because they tend to stay together on the same chromosome throughout meiosis unless separated by crossing over — this is **autosomal linkage**. When two linked genes are followed in a testcross of a double heterozygote (e.g. AaBb $\times$ aabb, where A/a and B/b are linked), the offspring are not produced in the equal $1{:}1{:}1{:}1$ ratio expected of independently assorting genes. Instead, most offspring show one of the two **parental** combinations of alleles (the combinations present together on each of the original parental chromosomes) in roughly equal, *large* numbers, while a smaller number show one of the two **recombinant** combinations (new combinations produced by crossing over between the two loci) in roughly equal, *small* numbers — parental types are always more frequent than recombinant types when genes are linked.

The proportion of recombinant offspring is called the **recombination frequency**, and it provides evidence for linkage: a recombination frequency well below the 50% expected of independent assortment indicates that two genes are linked (the closer together on the chromosome, the lower the recombination frequency, since crossing over is less likely to occur between them — this idea can be extended to estimate relative gene distances, i.e. genetic mapping, though this is not required in detail here).

Worked example: recombination frequency as evidence of linkage

In a testcross studying two genes for body colour (grey G/black g) and wing shape (normal V/vestigial v) in fruit flies, a doubly heterozygous fly (GgVv) is crossed with a doubly homozygous recessive fly (ggvv). Of 2300 offspring: 965 are grey, normal wings; 944 are black, vestigial wings; 206 are grey, vestigial wings; 185 are black, normal wings. *(a)* Identify the parental and recombinant phenotype classes. *(b)* Calculate the recombination frequency. *(c)* Explain what this recombination frequency indicates about the two genes.

(a) The two largest classes (grey/normal, 965, and black/vestigial, 944) match the two combinations present on the original parental chromosomes — these are the **parental** types. The two smaller classes (grey/vestigial, 206, and black/normal, 185) are the **recombinant** types, produced by crossing over between the two loci.

(b) Recombination frequency $= \dfrac{\text{recombinants}}{\text{total offspring}} = \dfrac{206 + 185}{2300} = \dfrac{391}{2300} \approx \mathbf{17.0\%}$.

(c) Because the recombination frequency (17%) is well below the 50% expected if the two genes assorted independently (i.e. if they were on different chromosomes, or very far apart on the same chromosome), this indicates the two genes are **linked** — located relatively close together on the same chromosome, so that crossing over between them is relatively infrequent.

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Các gen nằm **cùng một NST thường** (autosomal linkage) có xu hướng di truyền cùng nhau, không phân li độc lập, trừ khi bị tách ra bởi **trao đổi chéo**. Kết quả lai phân tích cho tỉ lệ kiểu hình **không đều**: hai loại **kiểu hình bố mẹ (parental)** chiếm đa số, hai loại **kiểu hình tái tổ hợp**

(recombinant) chiếm thiểu số. **Tần số tái tổ hợp** = số cá thể tái tổ hợp / tổng số cá thể — tần số càng thấp (so với 50% của phân li độc lập) thì hai gen càng liên kết chặt (càng gần nhau trên NST).

12.7 The chi-square (χ^2) test

Because real genetic crosses involve chance, observed offspring numbers rarely match an expected ratio (e.g. $3{:}1$ or $9{:}3{:}3{:}1$) exactly, even when the underlying genetics is correct. The **chi-square (χ^2) test** is used to decide whether an observed deviation from an expected ratio is small enough to be explained by chance alone, or large enough to be considered statistically significant (suggesting the expected ratio/hypothesis is wrong — e.g. due to linkage, epistasis, or a genuine error in the assumed genetics).

$$\chi^2 = \sum \frac{(O-E)^2}{E}$$

where O = observed count in a category and E = expected count in that category (calculated from the total sample size and the expected ratio). The calculated χ^2 value is compared against a **critical value** from a statistical table, read at a chosen significance level (conventionally $p = 0.05$) and the appropriate **degrees of freedom**, $df = (\text{number of categories}) - 1$.

Degrees of freedom (df)	Critical value at $p = 0.05$
1	3.841
2	5.991
3	7.815
4	9.488

Table 2. Critical values of χ^2 at $p = 0.05$ for small numbers of degrees of freedom.

Decision rule: the null hypothesis, H_0, always states that there is *no significant difference* between the observed and expected results (i.e. any difference is due to chance). If the calculated χ^2 is **less than** the critical value, H_0 is **accepted** — the data are consistent with the expected ratio. If the calculated χ^2 is **greater than** the critical value, H_0 is **rejected** — the deviation is statistically significant and unlikely to be due to chance alone (the expected ratio/hypothesis should be reconsidered).

Worked example 1: testing a monohybrid 3:1 ratio

A cross between two heterozygous pea plants (Tt $\times$ Tt) is expected to produce tall and dwarf offspring in a $3{:}1$ ratio. From a sample of 100 offspring, 82 are tall and 18 are dwarf. Test whether these results are consistent with the expected $3{:}1$ ratio.

H_0: there is no significant difference between the observed numbers of tall/dwarf plants and the numbers expected from a $3{:}1$ ratio (any difference is due to chance).

Expected numbers (from 100 offspring, $3{:}1$ ratio): tall $= \frac{3}{4} \times 100 = 75$; dwarf $= \frac{1}{4} \times 100 = 25$.

$$\chi^2 = \frac{(82-75)^2}{75} + \frac{(18-25)^2}{25} = \frac{49}{75} + \frac{49}{25} = 0.653 + 1.960 = \mathbf{2.61}$$

Degrees of freedom $= 2 - 1 = 1$; critical value at $p = 0.05$ is 3.841. Since $2.61 < 3.841$, we **accept** H_0: there is no significant difference between the observed and expected numbers — the data are consistent with a true $3{:}1$ ratio, and the small deviation observed is likely due to chance.

Worked example 2: testing a dihybrid 9:3:3:1 ratio

A dihybrid cross (RrYy × RrYy) of 320 offspring is expected to show a 9:3:3:1 phenotype ratio. The observed numbers are: 190 round yellow, 55 round green, 58 wrinkled yellow, 17 wrinkled green. Test whether the observed data fit the expected ratio.

H_0: there is no significant difference between the observed phenotype numbers and those expected from a 9:3:3:1 ratio.

Expected numbers (from 320 offspring, 9:3:3:1 ratio, 16 parts of 20 each): round yellow $= 9 \times 20 = 180$; round green $= 3 \times 20 = 60$; wrinkled yellow $= 3 \times 20 = 60$; wrinkled green $= 1 \times 20 = 20$.

$$\chi^2 = \frac{(190-180)^2}{180} + \frac{(55-60)^2}{60} + \frac{(58-60)^2}{60} + \frac{(17-20)^2}{20}$$

$$= \frac{100}{180} + \frac{25}{60} + \frac{4}{60} + \frac{9}{20} = 0.556 + 0.417 + 0.067 + 0.450 = \mathbf{1.49}$$

Degrees of freedom $= 4 - 1 = 3$; critical value at $p = 0.05$ is 7.815. Since $1.49 < 7.815$, we **accept** H_0: the observed data are consistent with the expected 9:3:3:1 ratio, supporting independent assortment of the two genes.

(!) Lỗi thường gặp: χ^2 **nhỏ hơn** giá trị tới hạn nghĩa là dữ liệu **phù hợp** với tỉ lệ kỳ vọng (chấp nhận H_0). χ^2 **lớn hơn** giá trị tới hạn nghĩa là sai khác **có ý nghĩa thống kê** — bác bỏ H_0 (ví dụ do gen liên kết, không phân li độc lập, hoặc epistasis). Luôn phát biểu H_0 theo **ngữ cảnh cụ thể** của phép lai (ví dụ "không có sự khác biệt có ý nghĩa giữa số liệu quan sát và tỉ lệ 9:3:3:1 kỳ vọng"), không chỉ viết chung chung.

12.8 The Hardy-Weinberg principle

The **Hardy-Weinberg principle** predicts that allele and genotype frequencies in a population will remain **constant** from generation to generation, provided a specific set of assumptions holds. This provides a mathematical baseline against which real populations can be compared, and it allows allele frequencies to be estimated from the observed frequency of a phenotype.

For a gene with two alleles, let p = frequency of the dominant allele and q = frequency of the recessive allele in the population, so that

$$p + q = 1.$$

Assuming random mating, the frequencies of the three possible genotypes are given by expanding $(p+q)^2$:

$$p^2 + 2pq + q^2 = 1,$$

where p^2 = frequency of homozygous dominant individuals, $2pq$ = frequency of heterozygous individuals (carriers, if the recessive allele causes a recessive condition), and q^2 = frequency of homozygous recessive individuals (i.e. the frequency of the recessive phenotype in the population, assuming complete dominance).

The Hardy-Weinberg equilibrium holds only if: (1) the population is **large** (to minimise random changes in allele frequency, i.e. genetic drift); (2) there is **no mutation** altering allele frequencies; (3) there is **no migration** of individuals into or out of the population (no gene flow); (4) **mating is random** with respect to the gene in question (no selective mate choice); (5) there is **no natural selection** acting on the gene (no genotype has a survival or reproductive advantage). If any of these assumptions is violated, allele frequencies may change between generations (evolution).

Worked example 1: allele and carrier frequency from incidence

A recessive genetic condition affects 1 in 2500 people in a population that is assumed to be in Hardy-Weinberg equilibrium. Calculate (a) the frequency of the recessive allele, (b) the frequency of the dominant allele, and (c) the frequency of unaffected carriers (heterozygotes) in the population.

(a) The frequency of the recessive phenotype (affected individuals) is $q^2 = \dfrac{1}{2500} = 0.0004$, so

$$q = \sqrt{0.0004} = \mathbf{0.02}\ (\text{i.e. } 2\%).$$

(b) $p = 1 - q = 1 - 0.02 = \mathbf{0.98}$ (i.e. 98%).
(c) Carrier (heterozygote) frequency $= 2pq = 2 \times 0.98 \times 0.02 = \mathbf{0.0392}$ (i.e. about 3.9%, or roughly 1 in 26 people are unaffected carriers of the recessive allele).

Worked example 2: incidence of albinism

Albinism (a recessive condition) occurs in 1 in $10\,000$ people in a population assumed to be in Hardy-Weinberg equilibrium. Calculate the frequency of the dominant allele and the percentage of the population who are heterozygous carriers.
$q^2 = \dfrac{1}{10\,000} = 0.0001 \Rightarrow q = \sqrt{0.0001} = 0.01$. So $p = 1 - q = 1 - 0.01 = \mathbf{0.99}$. Carrier frequency $= 2pq = 2 \times 0.99 \times 0.01 = 0.0198$, i.e. approximately **2.0**% of the population (about 1 in 51 people) are expected to be unaffected carriers.

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Nguyên lý Hardy-Weinberg: nếu quần thể đủ lớn, không đột biến, không di cư, giao phối ngẫu nhiên, không chọn lọc tự nhiên, thì tần số allele và kiểu gen không đổi qua các thế hệ, tuân theo $p + q = 1$ và $p^2 + 2pq + q^2 = 1$ (với p = tần số allele trội, q = tần số allele lặn). Từ tỉ lệ người mắc bệnh lặn (q^2) trong quần thể, ta suy ra $q = \sqrt{q^2}$, rồi $p = 1 - q$, và tần số người mang gen lặn không biểu hiện bệnh (dị hợp tử, carrier) là $2pq$ — thường lớn hơn nhiều so với tần số người thực sự mắc bệnh.

12.9 Practice questions

Bài tập luyện tập

State the stage of meiosis at which (a) crossing over occurs, and (b) homologous chromosomes separate from each other.

Lời giải chi tiết

(a) Crossing over occurs in **prophase I**, at chiasmata between non-sister chromatids of homologous chromosomes. (b) Homologous chromosomes separate in **anaphase I** (sister chromatids remain joined at this stage; they separate later, in anaphase II).

Bài tập luyện tập

Explain why independent assortment at metaphase I contributes to genetic variation, using the term "random orientation."

Lời giải chi tiết

At metaphase I, each bivalent (pair of homologous chromosomes) lines up at the equator independently of every other bivalent; for each pair, which homologue faces which pole is randomly orientated, unrelated to how any other pair is orientated. This means that when the homologues separate in anaphase I, each daughter cell receives an essentially random mixture of maternal and paternal chromosomes — different gametes from the same individual can therefore carry very different combinations of whole chromosomes, contributing to genetic variation among offspring.

Bài tập luyện tập

An organism has 4 pairs of homologous chromosomes ($n = 4$). Calculate the number of genetically distinct chromosome combinations possible in its gametes, considering independent assortment alone.

(A) 4
(C) 16
(B) 8
(D) 2

Lời giải chi tiết

Number of combinations $= 2^n = 2^4 =$ **16**. **(C)**.

Bài tập luyện tập

Explain why fertilisation is described as ”random,” and explain how this adds to the genetic variation already generated by meiosis.

Lời giải chi tiết

Fertilisation is random because, among the very large number of genetically different gametes that meiosis can produce in each parent, essentially any one sperm can fuse with any one egg — which particular gamete from each parent actually combines to form a zygote is a matter of chance. Since each parent can produce an enormous number of different gamete genotypes (via crossing over and independent assortment), and any combination of one sperm with one egg is possible, the number of possible genetically distinct offspring is the *product* of the number of possible gamete types from each parent — vastly increasing the overall genetic variation beyond what either parent's gametes show alone.

Bài tập luyện tập

Define, with an example, the terms (a) locus and (b) allele.

Lời giải chi tiết

(a) A **locus** is the specific, fixed position of a particular gene on a chromosome (e.g. the locus for the ABO blood group gene is at a specific position on chromosome 9). (b) An **allele** is one of the alternative versions of a gene that can occupy that locus, differing in DNA base sequence (e.g. I^A, I^B and i are three alleles of the ABO blood group gene).

Bài tập luyện tập

Distinguish between genotype and phenotype, and explain why two organisms with the same genotype might still show different phenotypes.

Lời giải chi tiết

Genotype is the allele composition an organism carries for a given gene (or genes); phenotype is the observable characteristic(s) that result. Two organisms with identical genotypes can show different phenotypes if they are exposed to different environmental conditions, since phenotype results from the interaction of genotype *and* environment (e.g. identical twins may differ in height or skin tone due to differences in diet or sun exposure).

Bài tập luyện tập

In pea plants, tall (T) is dominant to dwarf (t). A cross between two tall plants produces 126 tall and 41 dwarf offspring. Deduce the most likely genotypes of the two parent plants.

(A) TT $\times$ TT

(B) TT $\times$ tt

(C) Tt $\times$ Tt

(D) tt $\times$ tt

Lời giải chi tiết

The ratio $126{:}41$ is very close to $3{:}1$ ($126/41 \approx 3.07$), the classic monohybrid ratio produced when two heterozygotes are crossed (Tt $\times$ Tt $\rightarrow$ 1 TT : 2 Tt : 1 tt genotypes, 3 tall : 1 dwarf phenotypes). **(C)**.

Bài tập luyện tập

A tall pea plant of unknown genotype is crossed with a dwarf plant, and all 60 offspring are tall. State the most likely genotype of the originally tall parent, and explain your reasoning.

Lời giải chi tiết

Since a dwarf parent (tt) can only contribute a t allele, and *all* 60 offspring are tall, the unknown parent must have contributed only T alleles to its gametes — this is only possible if the unknown parent is homozygous dominant, **TT**. (If the unknown parent had been Tt, about half the offspring would be expected to be dwarf, which was not observed.)

Bài tập luyện tập

In guinea pigs, black coat (B) is dominant to white (b), and short hair (H) is dominant to long hair (h); the two genes are on different chromosomes. A doubly heterozygous guinea pig (BbHh) is crossed with another doubly heterozygous guinea pig (BbHh). State the expected phenotype ratio of the offspring.

(A) $1{:}1{:}1{:}1$

(B) $3{:}1$

(C) $9{:}3{:}3{:}1$

(D) $9{:}3{:}4$

Lời giải chi tiết

Since the two genes are on different chromosomes and assort independently, a dihybrid cross between two double heterozygotes always produces the classic $9{:}3{:}3{:}1$ phenotype ratio. **(C)**.

Bài tập luyện tập

Using the guinea pig cross above (BbHh $\times$ BbHh, black/short dominant), calculate the expected number of offspring with white, long hair (the double recessive phenotype) from a litter equivalent to 480 offspring (treat as a large sample for ratio purposes).

Lời giải chi tiết

The double recessive class (bbhh) makes up $1/16$ of the expected $9{:}3{:}3{:}1$ ratio. Expected number $= \dfrac{1}{16} \times 480 =$ **30** offspring with white, long hair.

Bài tập luyện tập

Explain, using a Punnett square in words, why a dihybrid cross between two organisms heterozygous at two independently-assorting loci produces sixteen equally likely combinations at fertilisation.

Lời giải chi tiết

Each doubly heterozygous parent (e.g. RrYy) produces four types of gamete in equal proportion (RY, Ry, rY, ry), because the two gene pairs assort independently of each other at meiosis. When gametes from two such parents combine at fertilisation, each of the four gamete types from one parent can combine with each of the four gamete types from the other parent, giving $4 \times 4 = 16$ equally likely combinations in total — the basis of the standard 4×4 dihybrid Punnett square.

Bài tập luyện tập

In a species of flower, red petals (C^R) and white petals (C^W) are codominant, giving pink petals in heterozygotes. A pink flower is crossed with a white flower. Predict the phenotype ratio of the offspring.

(A) All pink

(B) 1 red : 1 white

(C) 1 pink : 1 white

(D) 1 red : 1 pink

Lời giải chi tiết

Pink flower genotype: C^RC^W; white flower genotype: C^WC^W. Gametes: pink parent gives C^R or C^W (each $\frac{1}{2}$); white parent gives only C^W. Offspring: C^RC^W (pink) or C^WC^W (white), each with probability $\frac{1}{2}$ — a **1** pink : **1** white ratio. **(C)**.

Bài tập luyện tập

A woman with blood group O has a child with a man of unknown blood group. The child is blood group A. State the genotype of the child, and list the possible genotype(s)/phenotype(s) of the father.

Lời giải chi tiết

The mother (group O, genotype ii) can only contribute an i allele; since the child is group A, the child's genotype must be I^Ai, meaning the child received I^A from the father. The father must therefore carry at least one I^A allele — his genotype is either I^AI^A (phenotype A) or I^Ai (phenotype A), or I^AI^B (phenotype AB, if he also carries I^B). His blood group is therefore **A or AB** (he cannot be group B or O, as neither carries an I^A allele to pass on).

Bài tập luyện tập

Two parents, both blood group AB, have children. State the possible blood groups of their children and the expected proportions.

(A) All children are group AB

(B) 1 A : 2 AB : 1 B

(C) 1 A : 1 B : 1 AB : 1 O

(D) All children are either A or B, never AB

Lời giải chi tiết

Both parents are I^AI^B, so each produces gametes I^A or I^B (each $\frac{1}{2}$). Punnett square: I^AI^A (A), I^AI^B (AB), I^AI^B (AB), I^BI^B (B) — a genotype ratio of $1\,I^AI^A : 2\,I^AI^B : 1\,I^BI^B$, i.e. phenotype ratio **1** A : **2** AB : **1** B. Note that group O is impossible here, since neither parent carries an i allele. **(B)**.

Bài tập luyện tập

In a certain species of chicken, a cross between two black-feathered birds produces offspring in the ratio 9 black : 3 blue : 4 white (out of 16 parts), instead of the standard $9{:}3{:}3{:}1$ dihybrid ratio. Explain, in general terms, what this altered ratio suggests about the two genes involved.

Lời giải chi tiết

A $9{:}3{:}4$ ratio (rather than $9{:}3{:}3{:}1$) from a dihybrid cross is a classic signature of **epistasis**: one gene's recessive genotype (analogous to ee in the Labrador coat-colour example) masks or overrides the phenotypic expression of the second gene, causing two of the four standard dihybrid phenotype classes (each normally $3/16$ and $1/16$) to merge into a single visible phenotype class of $4/16$. This indicates the two genes interact in their effect on a single characteristic (feather colour), rather than acting completely independently as in a standard dihybrid cross.

Bài tập luyện tập

In summer squash, fruit colour is controlled by two interacting genes. A cross between two doubly heterozygous plants produces offspring in a ratio of 12 white : 3 yellow : 1 green (instead of $9{:}3{:}3{:}1$). Explain how this ratio could arise from epistasis, describing which genotype classes must have combined.

Lời giải chi tiết

A $12{:}3{:}1$ ratio arises when a dominant allele at one locus is epistatic — i.e. its presence (in either the homozygous *or* heterozygous dominant state) masks the effect of the second gene entirely, producing a single phenotype (white) regardless of the second gene's genotype. In the standard $9{:}3{:}3{:}1$ breakdown, this means the $9/16$ ($A\_B\_$) class and one of the $3/16$ classes

(e.g. A_bb) — both of which share the dominant allele at the epistatic locus — combine into a single $12/16$ white class, leaving the remaining $3/16$ class ($aaB\_$) as yellow and the $1/16$ class ($aabb$) as green.

Bài tập luyện tập

State the genotype (using X and Y notation) of (a) an unaffected male, (b) an affected male, and (c) a carrier female, for an X-linked recessive condition where X^H is the normal allele and X^h is the recessive disease allele.

Lời giải chi tiết

(a) Unaffected male: X^HY. (b) Affected male: X^hY. (c) Carrier female (unaffected but carries the allele): X^HX^h.

Bài tập luyện tập

A colour-blind man (X^bY) has children with a woman who is homozygous for normal colour vision (X^BX^B). State the expected phenotypes of their sons and daughters, and explain why the pattern differs between the two sexes.

Lời giải chi tiết

All sons receive their father's Y chromosome and their mother's X^B, giving genotype X^BY — all sons will have **normal colour vision** (they cannot inherit their father's X chromosome at all). All daughters receive their father's X^b and their mother's X^B, giving genotype X^BX^b — all daughters will have **normal colour vision** but will be **unaffected carriers**. The pattern differs between sexes because sons inherit their single X chromosome only from their mother, while daughters always inherit one X from each parent — so a colour-blind father can never pass the condition directly to a son, but will make every daughter at least a carrier.

Bài tập luyện tập

A carrier woman for haemophilia (X^HX^h) has children with a haemophiliac man (X^hY). Construct the cross and state the proportion of daughters expected to be affected by haemophilia.

(A) 0%
(B) 25%
(C) 50%
(D) 100%

Lời giải chi tiết

Mother's gametes: X^H or X^h (each $\frac{1}{2}$); father's gametes: X^h or Y (each $\frac{1}{2}$). Daughters always receive the father's X^h, plus either X^H or X^h from the mother: half of daughters are X^HX^h (carrier, unaffected) and half are X^hX^h (affected). So **50**$\%$ of daughters are expected to be affected. **(C)**.

Bài tập luyện tập

Explain why sex-linked recessive conditions such as haemophilia are far more common in males than in females within a population.

Lời giải chi tiết

Because the relevant gene is located on the X chromosome (with no equivalent allele on the much shorter Y chromosome), males are hemizygous for it — a male needs to inherit only **one** copy of the recessive allele (from his mother) to be affected, since he has no second X-linked allele that could mask it. A female, in contrast, has two X chromosomes and therefore needs to inherit the recessive allele from *both* parents to be affected; if she inherits only one copy, the normal dominant allele on her other X chromosome will mask it, and she is a healthy carrier rather than an affected individual. Since inheriting two copies is statistically much less likely than inheriting just one, the condition appears far more frequently in males.

Bài tập luyện tập

Two genes, P/p and Q/q, are known to be linked on the same autosome. A testcross of a double heterozygote (PpQq $\times$ ppqq) produces the following offspring: 410 PpQq, 390 ppqq, 100 Ppqq, 100 ppQq. Calculate the recombination frequency between the two genes.

Lời giải chi tiết

The two large classes (PpQq, 410, and ppqq, 390) are the parental types; the two small classes (Ppqq and ppQq, 100 each) are the recombinant types. Total offspring $= 410+390+100+100 = 1000$. Recombination frequency $= \dfrac{100+100}{1000} = \dfrac{200}{1000} = \mathbf{20}\%$.

Bài tập luyện tập

Explain why a recombination frequency of 20% (well below 50%) between two genes indicates linkage, and explain what would be different if the two genes were instead located on separate chromosomes.

Lời giải chi tiết

If two genes assort completely independently (e.g. because they are on different, non-homologous chromosomes), a testcross of a double heterozygote is expected to give all four offspring classes in equal (1:1:1:1) numbers — equivalent to a 50% "recombination" frequency, since there is no meaningful distinction between parental and recombinant classes. A recombination frequency of only 20% shows that the two parental-type combinations occur much more often than the two recombinant-type combinations, which only happens if the genes tend to be inherited together — i.e. if they are physically linked on the same chromosome, with crossing over between their loci occurring in only a minority (20%) of meioses.

Bài tập luyện tập

State the null hypothesis that should be used when carrying out a χ^2 test on the results of a genetic cross expected to show a $1{:}1$ ratio.

Lời giải chi tiết

H_0: there is no significant difference between the observed numbers of each phenotype and the numbers expected from a $1{:}1$ ratio; any difference observed is due to chance.

Bài tập luyện tập

A testcross expected to produce a $1{:}1$ ratio of offspring gives 30 of one phenotype and 20 of the other, out of 50 total. Calculate χ^2 and state, with reference to the critical value at $df = 1$ (3.841), whether the data fit the expected ratio.

(A) $\chi^2 = 1.0$; fits the expected ratio
(B) $\chi^2 = 2.0$; fits the expected ratio
(C) $\chi^2 = 2.0$; does not fit the expected ratio
(D) $\chi^2 = 4.0$; does not fit the expected ratio

Lời giải chi tiết

Expected numbers (from 50, $1{:}1$ ratio): 25 and 25.

$$\chi^2 = \frac{(30-25)^2}{25} + \frac{(20-25)^2}{25} = \frac{25}{25} + \frac{25}{25} = 1 + 1 = \mathbf{2.0}$$

Since $2.0 < 3.841$ (critical value, $df = 1$, $p = 0.05$), the deviation is not significant — the data **fit** the expected $1{:}1$ ratio. **(B)**.

Bài tập luyện tập

A cross expected to show a $1{:}2{:}1$ ratio (e.g. from a codominant gene) is tested using 120 offspring, expected numbers $30{:}60{:}30$. Observed numbers are $25{:}65{:}30$. Calculate χ^2 and give the appropriate degrees of freedom.

Lời giải chi tiết

$$\chi^2 = \frac{(25-30)^2}{30} + \frac{(65-60)^2}{60} + \frac{(30-30)^2}{30} = \frac{25}{30} + \frac{25}{60} + 0 = 0.833 + 0.417 + 0 = \mathbf{1.25}$$

Degrees of freedom $= 3 - 1 = 2$; critical value at $p = 0.05$ is 5.991. Since $1.25 < 5.991$, the deviation is not significant — the data are consistent with the expected $1{:}2{:}1$ ratio.

Bài tập luyện tập

A dihybrid cross expected to give a $9{:}3{:}3{:}1$ ratio in 160 offspring (expected: 90, 30, 30, 10) instead gives observed numbers 100, 20, 20, 20. Calculate χ^2, compare it with the critical value ($df = 3$, $p = 0.05$, 7.815), and suggest a biological explanation for the result.

Lời giải chi tiết

$$\chi^2 = \frac{(100-90)^2}{90} + \frac{(20-30)^2}{30} + \frac{(20-30)^2}{30} + \frac{(20-10)^2}{10}$$

$$= \frac{100}{90} + \frac{100}{30} + \frac{100}{30} + \frac{100}{10} = 1.111 + 3.333 + 3.333 + 10.0 = \mathbf{17.78}$$

Since $17.78 > 7.815$, the deviation is statistically significant — we **reject** H_0. The two "parental-type" classes (the largest, 100, and the two middle classes being noticeably depressed while the double-recessive-like class is inflated) suggest the two genes are not assorting independently; a plausible biological explanation is that the two genes are **linked** on the same chromosome, so that fewer recombinant offspring appear than would be expected under independent assortment.

Bài tập luyện tập

Explain why degrees of freedom for a χ^2 test are calculated as (number of categories -1) rather than simply the number of categories.

Lời giải chi tiết

Once the total sample size is fixed and the expected numbers in all but one category are known/calculated, the expected number in the final category is automatically determined (it must make up the remainder of the total) — it is not "free to vary" independently. Because one category's value is always fixed by the others, there are only (number of categories -1) independently varying categories, which is why degrees of freedom is calculated this way.

Bài tập luyện tập

A student carries out a χ^2 test and obtains a calculated value that is very close to, but just above, the critical value at $p = 0.05$. Explain what conclusion the student should draw, and what this implies about the probability of the observed deviation occurring by chance.

Lời giải chi tiết

If the calculated χ^2 value exceeds the critical value (even narrowly), the null hypothesis must formally be **rejected** at the $p = 0.05$ significance level — the deviation between observed and expected values is considered statistically significant. This means that, if the null hypothesis were actually true, a deviation this large (or larger) would be expected to occur by chance alone in fewer than 5% of samples — an unlikely enough occurrence that the null hypothesis is not accepted, even though the result is close to the borderline value.

Bài tập luyện tập

In a population in Hardy-Weinberg equilibrium, the frequency of the recessive allele $q = 0.3$. Calculate (a) the frequency of the dominant allele, and (b) the frequency of each of the three genotypes.

Lời giải chi tiết

(a) $p = 1 - q = 1 - 0.3 = \mathbf{0.7}$.
(b) Homozygous dominant: $p^2 = 0.7^2 = \mathbf{0.49}$ (49%). Heterozygous: $2pq = 2 \times 0.7 \times 0.3 = \mathbf{0.42}$ (42%). Homozygous recessive: $q^2 = 0.3^2 = \mathbf{0.09}$ (9%). (Check: $0.49 + 0.42 + 0.09 = 1.00$.)

Bài tập luyện tập

A recessive genetic condition occurs in 1 in 100 people in a population assumed to be in Hardy-Weinberg equilibrium. Calculate the percentage of the population who are unaffected carriers.

(A) 1%
(B) 9%
(C) 18%
(D) 81%

Lời giải chi tiết

$q^2 = \dfrac{1}{100} = 0.01 \Rightarrow q = \sqrt{0.01} = 0.1$. $p = 1 - 0.1 = 0.9$. Carrier frequency $= 2pq =$

$2 \times 0.9 \times 0.1 = 0.18 =$ **18**%. **(C)**.

Bài tập luyện tập

A recessive condition occurs in 1 in 1600 people in a population in Hardy-Weinberg equilibrium. Calculate (a) the frequency of the recessive allele, (b) the frequency of the dominant allele, and (c) the percentage of the population expected to be heterozygous carriers.

Lời giải chi tiết

(a) $q^2 = \dfrac{1}{1600} = 0.000625 \Rightarrow q = \sqrt{0.000625} =$ **0.025** (i.e. 2.5%).
(b) $p = 1 - q = 1 - 0.025 =$ **0.975** (i.e. 97.5%).
(c) Carrier frequency $= 2pq = 2 \times 0.975 \times 0.025 = 0.04875 \approx$ **4.9**% of the population.

Bài tập luyện tập

A recessive condition occurs in 1 in 25 people in an isolated population assumed to be in Hardy-Weinberg equilibrium. Calculate the frequency of homozygous dominant individuals in this population.

Lời giải chi tiết

$q^2 = \dfrac{1}{25} = 0.04 \Rightarrow q = \sqrt{0.04} = 0.2$. $p = 1 - q = 1 - 0.2 = 0.8$. Homozygous dominant frequency $= p^2 = 0.8^2 = 0.64$, i.e. **64**% of the population is expected to be homozygous dominant.

Bài tập luyện tập

Explain why the Hardy-Weinberg equations can only be used to reliably estimate real-world allele frequencies if certain assumptions are reasonably well satisfied; give two such assumptions and explain briefly why each matters.

Lời giải chi tiết

Two of the required assumptions are: (1) **no natural selection** on the gene in question — if one genotype had a survival or reproductive advantage, its allele frequency would systematically increase across generations, violating the assumption of constant allele frequencies. (2) **random mating** with respect to the gene — if individuals preferentially mated with partners of a particular genotype (non-random/assortative mating), genotype frequencies would deviate from the $p^2 : 2pq : q^2$ prediction even if allele frequencies themselves stayed the same. If these (or the other required assumptions — large population size, no mutation, no migration) do not hold, calculated allele frequencies from the q^2 method may not accurately reflect the true underlying frequencies, and real allele frequencies may be changing over time (evolving).

Bài tập luyện tập

In a population of $10\,000$ people, 400 are affected by a recessive genetic condition, and the population is assumed to be in Hardy-Weinberg equilibrium. Calculate the number of people in the population expected to be unaffected heterozygous carriers.

Lời giải chi tiết

Frequency of the affected (homozygous recessive) phenotype: $q^2 = \dfrac{400}{10\,000} = 0.04 \Rightarrow q = \sqrt{0.04} = 0.2$. Then $p = 1 - q = 1 - 0.2 = 0.8$. Carrier frequency $= 2pq = 2 \times 0.8 \times 0.2 = 0.32$ (32%). Number of carriers $= 0.32 \times 10\,000 =$ **3200** people — note this is 8 times the number actually affected (400), illustrating how a rare recessive condition can still have a substantial "hidden" carrier frequency in the population.

Selection, Evolution, Biodiversity and Conservation

A2 Level

Mục tiêu Unit: Nguồn gốc biến dị và chọn lọc tự nhiên (ổn định hoá, định hướng, phân hoá); khái niệm loài sinh học và hình thành loài (allopatric/sympatric); liên hệ Hardy–Weinberg với tiến hoá; bằng chứng tiến hoá; ba cấp độ đa dạng sinh học; hệ thống phân loại và danh pháp hai phần; hệ ba lãnh giới và hệ năm giới; phân loại phát sinh chủng loại; chỉ số đa dạng Simpson; phương pháp lấy mẫu bằng ô mẫu và tuyến cắt; các mối đe doạ và chiến lược bảo tồn tại chỗ/chuyển vị.

Part A --- Selection and Evolution

13.1 Sources of variation

Natural selection can only act on **heritable variation** that already exists within a population. Three processes generate this variation; only one of them creates genuinely new alleles.

Three sources of variation

Mutation is the *ultimate* source of all new alleles: a random, spontaneous change in the base sequence of DNA (gene mutation — substitution, insertion, deletion) or in chromosome structure/number, producing an allele that did not exist before. **Meiotic crossing over** (in prophase I, homologous non-sister chromatids exchange DNA segments, creating new combinations of alleles on a chromosome) and **independent assortment** (the random orientation of each homologous pair at metaphase I) do *not* create new alleles — they only *reshuffle existing alleles* into new combinations. **Random fertilisation** (any one of millions of genetically-varied sperm may fuse with any one of a smaller number of genetically-varied eggs) further multiplies the number of possible allele combinations in the offspring generation. (Full derivations of crossing over and the 2^n rule for independent assortment are covered in the Inheritance chapter.)

VN **GIẢI THÍCH TIẾNG VIỆT**

Ba nguồn gốc biến dị: **đột biến** là nguồn gốc *duy nhất* tạo ra alen hoàn toàn mới (thay đổi ngẫu nhiên trình tự base của DNA hoặc cấu trúc/số lượng nhiễm sắc thể). **Trao đổi chéo** trong giảm phân I và **phân li độc lập** ở kỳ giữa I *không* tạo alen mới — chỉ sắp xếp lại các alen đã có thành tổ hợp mới. **Thụ tinh ngẫu nhiên** làm tăng thêm số tổ hợp alen có thể có ở đời con. Đây là biến dị *di truyền được* — nguyên liệu thô để chọn lọc tự nhiên tác động lên.

13.2 The concept of natural selection

Natural selection — the logical chain

(1) Heritable variation exists within a population for a given trait. (2) The environment imposes a **selection pressure** (e.g. a predator, a limited food/nutrient supply, a pathogen, a toxin, a changing climate). (3) Individuals whose alleles give them a phenotype better suited to that pressure survive and/or reproduce more successfully than other individuals (**differential survival and reproduction**). (4) Those individuals pass their advantageous alleles to a disproportionately large share of the next generation. (5) Repeated over many generations, the frequency of the advantageous allele(s) rises in the population's gene pool — this cumulative, population-level change in allele frequency *is* evolution by natural selection.

(!) Lỗi thường gặp: Natural selection acts on *populations over generations*, never on individuals within their own lifetime. An individual organism does not "evolve" or "adapt" in response to a pressure it experiences; it either survives and reproduces, or it does not. Likewise, a mutation conferring an advantage (e.g. antibiotic resistance) must already exist *before* the selection pressure appears — the pressure does not cause the useful mutation to happen, it only determines which existing variants survive.

VN **GIẢI THÍCH TIẾNG VIỆT**

Chọn lọc tự nhiên: biến dị di truyền có sẵn trong quần thể → áp lực chọn lọc từ môi trường → cá thể mang alen phù hợp hơn sống sót/sinh sản tốt hơn → alen đó được truyền cho nhiều đời con hơn → qua nhiều thế hệ, tần số alen có lợi tăng dần trong quần thể. Chọn lọc tự nhiên tác động lên **quần thể qua nhiều thế hệ**, không phải lên từng cá thể riêng lẻ trong đời nó; đột biến có lợi phải **đã tồn tại sẵn** trước khi áp lực chọn lọc xuất hiện — chọn lọc không "tạo ra" đột biến theo nhu cầu.

13.3 Patterns of selection: stabilising, directional and disruptive

A selection pressure can act on a continuously-varying (normally distributed) phenotype in three characteristic ways.

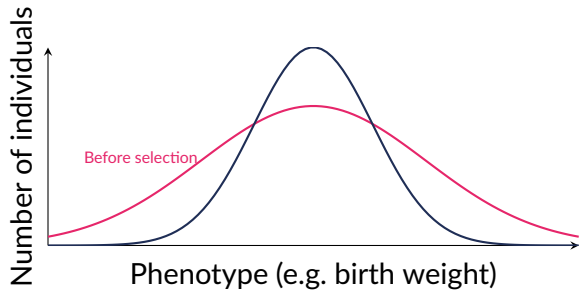

Figure 13.1 — Stabilising selection. Both phenotypic extremes are selected against; the intermediate phenotype is favoured. The mean is unchanged but variance decreases (curve narrows and heightens). Example: human birth weight — babies that are too small (poor thermoregulation/reserves) or too large (difficult delivery) have historically had lower survival than average-weight babies.

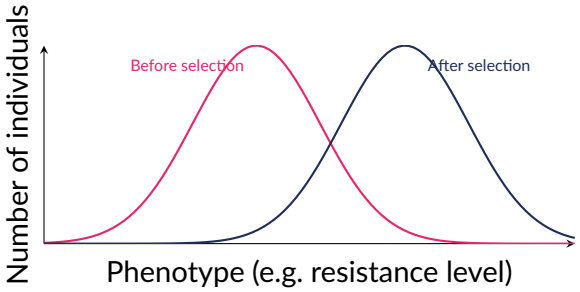

Figure 13.2 — Directional selection. One phenotypic extreme is favoured; the population mean shifts steadily toward it over generations. Examples: evolution of antibiotic resistance in bacteria, pesticide resistance in insects, industrial melanism in the peppered moth *Biston betularia*.

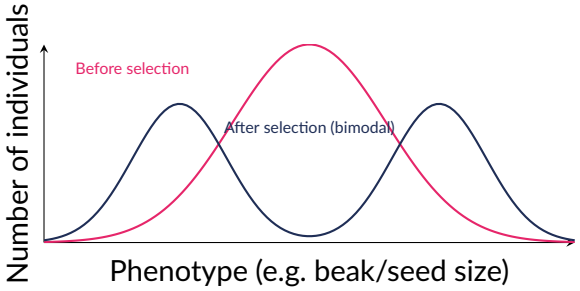

Figure 13.3 — Disruptive selection. Both extremes are favoured *over* the intermediate phenotype, which becomes disadvantaged (e.g. an intermediate seed-cracking beak size is worse at both very hard and very small seeds than either specialist extreme). The population can become bimodal and, if mating becomes non-random with respect to the two extremes, may eventually split into two reproductively isolated groups (sympatric speciation).

Stabilising selection — favours the *intermediate* phenotype; removes both extremes; reduces variance; mean unchanged. **Directional selection** — favours *one* extreme; shifts the mean toward it; variance may initially increase then narrow around the new mean. **Disruptive selection** — favours *both* extremes over the intermediate; can produce a bimodal distribution and, under continued reproductive isolation between the two peaks, may lead to sympatric speciation.

Ví dụ mẫu — interpreting human birth weight data

Historical UK survey data (pre-modern medicine) show infant survival is highest for birth weights close to 3.4 kg, and lower for both smaller (< 2.5 kg) and larger (> 4.5 kg) babies. Identify the pattern of selection and explain the expected effect on the population's variance over time.

Both phenotypic extremes (very low and very high birth weight) are selected against, while the intermediate value is favoured — this is **stabilising selection**. Because both tails of the distribution are removed each generation while the mean survives unchanged, the **variance of the trait decreases** over successive generations: the distribution becomes narrower/taller around the same mean, exactly as shown in Figure 13.1.

Ví dụ mẫu — directional selection: peppered moth and antibiotic resistance

Before the Industrial Revolution, the pale (*typica*) form of the peppered moth *Biston betularia* was camouflaged against light, lichen-covered bark, while the rare dark (*melanic*, *carbonaria*) form was easily spotted and eaten by birds. Industrial pollution killed the lichen and blackened tree trunks with soot; the melanic form became camouflaged instead, and its frequency rose sharply within a few decades. Explain why this — and the modern evolution of antibiotic re-

sistance in bacteria — are both classified as directional selection.

In both cases, a change in the environment (sooty bark; presence of an antibiotic) creates a selection pressure that favours *one* phenotypic extreme (dark colouration; resistance) that already existed at low frequency in the population, over the previously-favoured alternative. Individuals with the favoured phenotype survive and reproduce disproportionately, so the allele frequency for that phenotype rises steadily across generations, shifting the population mean toward that extreme — the defining signature of **directional selection**. Neither moths nor bacteria "chose" to change; the melanic allele and resistance alleles were already present at low frequency through pre-existing mutation, and the environment simply selected for organisms that already carried them.

13.4 Case study: the evolution of antibiotic resistance

Stepwise mechanism

(1) In a large bacterial population, **random mutation** (occurring independently of, and before, any antibiotic exposure) confers resistance to a particular antibiotic in a small number of cells. (2) The population is exposed to the antibiotic. (3) Susceptible (non-resistant) bacteria are killed; resistant bacteria survive because the antibiotic can no longer disable their target process (e.g. cell wall synthesis, protein synthesis). (4) Surviving resistant bacteria proliferate rapidly (bacterial generation times are short — often 20–30 minutes), and because resistance alleles are heritable, the daughter population is predominantly resistant. (5) Repeated or incomplete courses of antibiotic exposure across a population (e.g. a hospital, or livestock given routine low-dose antibiotics) repeat this cycle, and the frequency of the resistance allele in the overall bacterial population rises further with each exposure.

(!) Lỗi thường gặp: This is **natural selection**, not bacteria "trying to become resistant" or "learning" to survive. The antibiotic does not cause the resistance mutation to appear; it merely acts as a selection pressure that kills susceptible cells, leaving behind (and allowing to multiply) the already-resistant minority. This same logic explains pesticide resistance in insect populations and herbicide resistance in weeds.

VN **GIẢI THÍCH TIẾNG VIỆT**

Cơ chế tiến hoá đề kháng kháng sinh: đột biến kháng thuốc xuất hiện **ngẫu nhiên trước đó** ở một số ít vi khuẩn → tiếp xúc kháng sinh giết chết vi khuẩn mẫn cảm → vi khuẩn kháng thuốc sống sót và sinh sản nhanh → tần số alen kháng thuốc trong quần thể tăng lên qua mỗi đợt tiếp xúc. Đây là **chọn lọc tự nhiên**: kháng sinh không "khiến" vi khuẩn kháng thuốc xuất hiện, mà chỉ chọn lọc những cá thể đã mang sẵn alen kháng thuốc.

13.5 The species concept and its limitations

The biological species concept

A **species** is defined as a group of organisms capable of interbreeding to produce **fertile** offspring, and which is reproductively isolated from other such groups (i.e. they do not normally interbreed with, or cannot produce fertile offspring with, members of other species).

The biological species concept is powerful but has recognised limitations:

- **Asexually-reproducing organisms** (many bacteria, some plants and protoctists) never interbreed at all, so "capable of interbreeding" cannot be applied directly — these organisms are instead grouped by morphological and, increasingly, molecular (DNA sequence) similarity.
- **Ring species**: a chain of neighbouring populations arranged in a geographic ring around a barrier (e.g. a mountain range or the Arctic Circle), where each adjacent population can interbreed with its immediate neighbours, but the two populations at the ends of the ring — where the ring closes and they meet — cannot interbreed. It is then ambiguous where one "species" ends and the next begins.
- **Fertile hybrids**: occasionally, individuals from what are otherwise treated as two separate species produce viable, fertile hybrid offspring (e.g. some hybridising plant species, or hybrid crosses between closely related large cats or bears), blurring the sharp boundary the concept assumes.

VN **GIẢI THÍCH TIẾNG VIỆT**

Khái niệm loài sinh học: nhóm sinh vật có thể giao phối với nhau sinh ra đời con **hữu thụ**, và cách li sinh sản với các nhóm khác. Hạn chế: sinh vật **sinh sản vô tính** không giao phối nên khó áp dụng; **loài vòng** (ring species) — các quần thể liền kề giao phối được với nhau nhưng hai quần thể ở hai đầu vòng (khi gặp nhau) lại không giao phối được, gây mơ hồ về ranh giới loài; **con lai hữu thụ** giữa hai "loài" riêng biệt cũng làm mờ ranh giới này.

13.6 Speciation: allopatric and sympatric

A new species arises when populations diverge genetically until they become **reproductively isolated** — no longer able to interbreed to produce fertile offspring, even if brought back into contact.

	Allopatric speciation	Sympatric speciation
Geographic separation	**Required** — a physical barrier (river, mountain range, ocean, land bridge) splits one population into two	**Not required** — occurs within the same geographic area
Mechanism	Each isolated population accumulates independent genetic changes (different mutations, different local selection pressures, genetic drift) until they can no longer interbreed	Reproductive isolation arises through disruptive selection (different niches/resources), polyploidy (instant chromosome-number change), or behavioural/temporal isolation (different courtship signals or breeding times)
Typical timescale	Usually gradual, over many generations	Can be gradual (disruptive selection) or effectively instantaneous (polyploidy)
Example	Two fish populations isolated in separate lakes after a land bridge forms, diverging until they can no longer interbreed	A tetraploid plant arising by chromosome doubling that cannot backcross with its diploid parent species

Table 13.1 — Allopatric versus sympatric speciation.

Ví dụ mẫu — polyploidy as instant sympatric speciation

A diploid plant species ($2n = 14$) occasionally hybridises with a related diploid species ($2n = 16$) growing in the same field, producing a sterile hybrid ($2n = 15$, since the mismatched chromosomes cannot pair properly at meiosis). A spontaneous chromosome-doubling error in this hybrid produces a fertile **allopolyploid** with $4n = 30$ chromosomes. Explain why this new plant is immediately a new, sympatric species.

The allopolyploid ($4n = 30$) can self-fertilise or mate with other identical allopolyploids and produce fertile offspring (its chromosomes now have complete pairing partners at meiosis), but it **cannot** produce fertile offspring by backcrossing with either original diploid parent species (meiosis in a triploid-type hybrid, e.g. $3n$, fails to pair chromosomes correctly). It is therefore reproductively isolated from both parent species *immediately*, in a single generation, without any geographic separation — a textbook case of **sympatric speciation** via polyploidy, common in flowering plants.

VN **GIẢI THÍCH TIẾNG VIỆT**

Hình thành loài khác khu (allopatric): rào cản địa lý tách quần thể thành hai, mỗi bên tiến hoá độc lập (đột biến khác nhau, áp lực chọn lọc khác nhau, phiêu bạt di truyền) đến khi cách li sinh sản hoàn toàn. **Hình thành loài cùng khu (sympatric)**: cách li sinh sản xuất hiện mà *không cần* rào cản địa lý — do chọn lọc phân hoá, đa bội hoá (đặc biệt phổ biến ở thực vật, có thể xảy ra ngay lập tức), hoặc cách li tập tính/thời điểm sinh sản.

13.7 Hardy--Weinberg and the genetic basis of evolution

Recall from the Inheritance chapter that, for a gene with two alleles at frequencies p and q ($p+q=1$) in a population at genetic equilibrium: $p^2 + 2pq + q^2 = 1$, where p^2, $2pq$ and q^2 are the expected genotype frequencies (homozygous dominant, heterozygous, homozygous recessive). This equilibrium holds only if five conditions are met: a very large population, random mating, no mutation, no migration, and no selection.

Evolution defined genetically

Evolution is, at its most fundamental genetic level, a **change in allele frequencies in a population's gene pool over successive generations**. Any real population that violates one or more Hardy–Weinberg assumptions will show changing allele frequencies — i.e. it is evolving. Each assumption corresponds to a real evolutionary force:

- **No selection → natural selection**: alleles associated with higher survival/reproductive success increase in frequency (Sections 13.2–13.4).
- **Very large population → genetic drift**: in small populations, allele frequencies can change by pure chance sampling error between generations (e.g. the **founder effect**, when a few individuals establish a new isolated population, and the **bottleneck effect**, when a population crashes and only a non-representative genetic sample survives).
- **No migration → gene flow**: individuals (and their alleles) moving into or out of a population change local allele frequencies.
- **No mutation → mutation**: continuously introduces new alleles, albeit typically very slowly relative to selection/drift.

Ví dụ mẫu — linking Hardy–Weinberg to evolution

In generation 1 of an insect population, the allele for insecticide resistance (R) has frequency $q = 0.20$ (so $p = 0.80$ for the susceptible allele). After ten years of repeated insecticide spraying, a second survey finds $q = 0.65$. (a) Has evolution occurred, in the genetic sense? (b) What pattern of selection is most consistent with this change, and which Hardy–Weinberg assumption has clearly been violated?

(a) Yes: the allele frequency of the population's gene pool has changed from $q = 0.20$ to $q = 0.65$ across generations — by definition, this *is* evolution.

(b) The steady rise in one allele's frequency, driven by a consistent selective pressure (the insecticide) favouring one phenotypic extreme (resistance), is characteristic of **directional selection**. The Hardy–Weinberg assumption of **no selection** has been violated (insecticide spraying is a strong, sustained selection pressure); note that the assumption of a very large population is also worth checking, but the directional, sustained, targeted nature of the change points to selection rather than random drift as the dominant cause.

VN **GIẢI THÍCH TIẾNG VIỆT**

Tiến hoá, xét ở cấp độ gen, chính là **sự thay đổi tần số alen** trong vốn gen của quần thể qua các thế hệ. Quần thể ở trạng thái cân bằng Hardy–Weinberg cần: quần thể rất lớn, giao phối ngẫu nhiên, không đột biến, không di cư, không chọn lọc. Khi một trong các điều kiện này bị vi phạm trong thực tế — **chọn lọc tự nhiên**, **phiêu bạt di truyền** (đặc biệt ở quần thể nhỏ — hiệu ứng người sáng lập, hiệu ứng thắt cổ chai), **di nhập gen** (di cư), hoặc **đột biến** — tần số alen sẽ thay đổi, tức là quần thể đang tiến hoá.

13.8 Evidence for evolution

Comparative anatomy: *homologous structures* (same underlying skeletal plan, different function — e.g. the pentadactyl limb shared by all tetrapod vertebrates) indicate common ancestry; *analogous structures* (similar function, different underlying structure/evolutionary origin — e.g. insect wings vs. bird wings) arise by **convergent evolution** under similar selection pressures and are *not* evidence of a recent common ancestor. **Molecular evidence**: the greater the similarity between two species' DNA, mRNA or protein (e.g. cytochrome c) sequences, the more recently they shared a common ancestor — this underlies molecular phylogenetics. **The fossil record**: older rock strata (deeper, by the principle of superposition) contain progressively different, often simpler or more primitive fossils, and transitional fossils (e.g. in the horse lineage) document gradual anatomical change over geological time. **Direct observation**: evolution has been observed happening in real time, e.g. the rapid spread of antibiotic resistance in bacteria, and the measured shift in Galápagos finch beak depth (Grant & Grant's long-term field studies) tracking drought-driven directional selection on seed hardness.

Ví dụ mẫu — molecular evidence for relatedness

The table below gives the approximate percentage similarity of a stretch of DNA sequence between humans and four other primates.

Species	% DNA sequence similarity to humans
Chimpanzee (*Pan troglodytes*)	98.8%
Gorilla (*Gorilla gorilla*)	98.3%
Orangutan (*Pongo pygmaeus*)	96.9%
Rhesus macaque (*Macaca mulatta*)	93.0%

Which species is most closely related to humans, and why?

The **chimpanzee** is most closely related: the higher the percentage sequence similarity, the fewer mutational differences have accumulated since the two lineages diverged from a shared ancestor, implying the **most recent common ancestor**. The ranking of similarity (chimpanzee > gorilla > orangutan > rhesus macaque) also indicates the order in which each lineage branched off from the line leading to modern humans — the basis of molecular phylogenetic trees.

Part A --- Practice

Bài tập luyện tập

Which of the following is the *ultimate* source of all new alleles in a population?

(A) Independent assortment at meiosis I

(B) Crossing over between non-sister chromatids

(C) Mutation

(D) Random fertilisation

Lời giải chi tiết

Crossing over and independent assortment only reshuffle alleles that already exist; random fertilisation further combines existing gametes. Only **mutation** creates a genuinely new allele. **(C)**.

Bài tập luyện tập

Explain why crossing over during meiosis I increases genetic variation, without itself creating new alleles.

Lời giải chi tiết

Crossing over exchanges DNA segments between non-sister chromatids of a homologous pair, at points called chiasmata. This creates chromatids with **new combinations of existing alleles** (e.g. an allele for trait 1 from the maternal chromosome now sits alongside an allele for trait 2 from the paternal chromosome) — it recombines alleles that were already present in the population rather than generating any new allele itself.

Bài tập luyện tập

Put the following steps of natural selection into the correct logical order: (i) advantageous alleles increase in frequency over generations; (ii) heritable variation exists in a population; (iii) individuals with advantageous alleles survive/reproduce more successfully; (iv) a selection pressure is present in the environment.

Lời giải chi tiết

Correct order: (ii) variation exists → (iv) a selection pressure acts → (iii) individuals with favourable alleles survive/reproduce disproportionately → (i) the frequency of those alleles rises across generations.

Bài tập luyện tập

A gardener records seed mass in a wild population of a plant over several generations, noticing that intermediate-mass seeds germinate best (too small = insufficient food reserve; too large = poor dispersal), while both very light and very heavy seeds germinate poorly. Which pattern of selection is this, and what happens to the variance of seed mass over time?

(A) Directional selection; variance increases

(B) Disruptive selection; the population becomes bimodal

(C) Stabilising selection; variance decreases

(D) No selection is occurring

Lời giải chi tiết

The intermediate phenotype is favoured and both extremes are selected against — **stabilising selection**. Because both tails are progressively removed, the distribution narrows around the unchanged mean, so **variance decreases**. **(C)**.

Bài tập luyện tập

On a graph of a directional selection event, which feature of the ”after selection” curve, compared with ”before selection”, is diagnostic of directional (rather than stabilising) selection?

(A) The peak becomes taller with no change in position

(B) The peak height decreases but position is unchanged

(C) The mean/peak position shifts toward one extreme of the original distribution

(D) The distribution becomes bimodal

Lời giải chi tiết

Directional selection favours one extreme, so the entire distribution’s mean/peak visibly **shifts** toward that extreme over generations (Figure 13.2), unlike stabilising selection (narrows, same mean) or disruptive selection (splits into two peaks). **(C)**.

Bài tập luyện tập

A population of moths contains both pale and dark forms. After a forest fire blackens tree bark for a wide area, describe, in your own words, the expected change in this population over the following decade, and name the pattern of selection.

Lời giải chi tiết

Dark moths, now camouflaged against blackened bark, are less likely to be spotted and eaten by predatory birds than pale moths, which now stand out. Dark moths therefore survive and reproduce more successfully, passing on alleles for dark colouration to a larger share of each subsequent generation. Over the following decade, the proportion of dark moths in the population is expected to rise steadily while pale moths decline — the population mean phenotype

shifts toward the dark extreme. This is **directional selection** (directly analogous to industrial melanism in the peppered moth).

Bài tập luyện tập

A single mutation confers antibiotic resistance in a bacterium *before* any antibiotic is ever introduced into its environment. A microbiologist then applies the antibiotic and observes the resistant strain becomes dominant within days. Which statement best explains this observation?

(A) The antibiotic caused the bacteria to develop resistance as a direct physiological response

(B) The antibiotic selected for a resistance allele that was already present by chance mutation, killing susceptible cells and allowing resistant cells to proliferate

(C) Bacteria communicated and collectively decided to become resistant

(D) This cannot be natural selection because it happened too quickly

Lời giải chi tiết

The resistance mutation pre-existed the antibiotic exposure (as stated); the antibiotic then acted purely as a **selection pressure**, killing susceptible bacteria and allowing the pre-existing resistant minority to survive and rapidly multiply (aided by very short bacterial generation times). This is classic natural/directional selection, not an induced or "chosen" response. **(B)**.

Bài tập luyện tập

State the biological species concept, and explain one limitation of applying it to bacteria.

Lời giải chi tiết

The biological species concept defines a species as a group of organisms capable of interbreeding to produce fertile offspring, reproductively isolated from other such groups. This concept cannot be meaningfully applied to bacteria because they reproduce **asexually** (binary fission) and do not interbreed at all — "capable of interbreeding" has no clear meaning for them, so bacterial species are instead delimited using morphological, biochemical and molecular (DNA/rRNA sequence) similarity.

Bài tập luyện tập

In a "ring species", population A can interbreed with neighbouring population B, B can interbreed with C, and C can interbreed with D, but A and D — which meet where the geographic ring closes — cannot interbreed. What problem does this create for the biological species concept?

(A) None; A and D are clearly two different species and B, C are irrelevant

(B) It creates ambiguity, since adjacent populations can interbreed (suggesting one species) while the end populations cannot (suggesting two species)

(C) It proves the biological species concept always works perfectly

(D) It shows that geographic isolation is impossible in nature

Lời giải chi tiết

Ring species reveal that reproductive compatibility is not always a clean, transitive, all-or-nothing property: neighbouring populations along the ring interbreed successfully, implying they belong to one continuous species, yet the two end populations cannot interbreed, implying they are separate species — there is no single, non-arbitrary point along the ring where one species clearly becomes another. **(B)**.

Bài tập luyện tập

Two fish populations, formerly one interbreeding population in a single large lake, become permanently separated when tectonic uplift creates a mountain range dividing the lake into two smaller lakes. After $50\,000$ years apart, individuals from the two lakes can no longer produce fertile offspring. Name and justify the type of speciation.

Lời giải chi tiết

This is **allopatric speciation**: a physical geographic barrier (the new mountain range) split one interbreeding population into two, after which each population accumulated independent genetic changes (different mutations arising, different local selection pressures, and/or genetic drift) in isolation from one another, eventually resulting in reproductive isolation.

Bài tập luyện tập

A population of insects feeding on a single host plant species experiences a mutation allowing some individuals to also feed on, and eventually prefer, a second host plant species growing in the same field. Over time, individuals preferring different host plants mate assortatively (with others on the same host) and evolve into two reproductively isolated groups, with no geographic barrier ever forming. Name this type of speciation and the selective process that likely drove it.

(A) Allopatric speciation, driven by stabilising selection

(B) Sympatric speciation, likely driven by disruptive selection on the two host-plant "niches"

(C) This cannot be speciation at all, since there was no physical barrier

(D) Sympatric speciation, but only possible via polyploidy

Lời giải chi tiết

No geographic barrier was involved, so this is **sympatric** speciation. The two host-plant niches acted as divergent selection pressures on feeding/mating behaviour, favouring the two extremes (specialising on one plant or the other) over any generalist intermediate — **disruptive selection** — and assortative mating then reinforced reproductive isolation between the two host-associated groups. **(B)**.

Bài tập luyện tập

Explain, with an example, how polyploidy can cause instantaneous sympatric speciation in plants.

Lời giải chi tiết

Polyploidy is a change in whole chromosome number (e.g. from diploid $2n$ to tetraploid $4n$), which can arise by a spontaneous error in meiosis or mitosis, or by chromosome doubling in a sterile interspecific hybrid. A polyploid individual usually cannot produce fertile offspring by backcrossing with its diploid parent(s), because their chromosomes cannot pair correctly at meiosis (mismatched chromosome numbers), but it *can* interbreed successfully with other individuals sharing the same new chromosome number. This makes the polyploid reproductively isolated from its parent species in a single generation, without any geographic separation — an instant new (sympatric) species, common in flowering plants (e.g. many cultivated wheat and cotton species are polyploid).

Bài tập luyện tập

In a population at Hardy–Weinberg equilibrium, the recessive phenotype (genotype aa) occurs in 4% of individuals. Calculate the frequency of the dominant allele, A.

(A) $p = 0.2$

(B) $p = 0.8$

(C) $p = 0.96$

(D) $p = 0.4$

Lời giải chi tiết

$q^2 = 0.04 \Rightarrow q = \sqrt{0.04} = 0.2$. Then $p = 1 - q = 1 - 0.2 =$ **0.8**. **(B)**.

Bài tập luyện tập

Using the previous result ($p = 0.8$, $q = 0.2$), calculate the percentage of the population expected to be heterozygous carriers, and verify that all genotype frequencies sum to 1.

Lời giải chi tiết

$2pq = 2 \times 0.8 \times 0.2 = 0.32 =$ **32**$\%$ heterozygous. Check: $p^2 + 2pq + q^2 = 0.64 + 0.32 + 0.04 = 1.00$ ✓.

Bài tập luyện tập

Which of the five Hardy–Weinberg assumptions is violated when a small population of ten surviving deer re-establishes an entire new population after a harsh winter wipes out the rest, by chance leaving an unrepresentative sample of the original gene pool?

(A) No mutation — this is an example of a new mutation appearing

(B) No migration — this is gene flow

(C) Very large population size — this is genetic drift (a bottleneck effect)

(D) No selection — this is natural selection

Lời giải chi tiết

A small surviving population, whose allele frequencies differ from the original population purely by chance (not because of any survival advantage), violates the "very large population" assumption — a textbook **bottleneck effect**, a form of **genetic drift**. **(C)**.

Bài tập luyện tập

A few individuals of a bird species are blown far off course by a storm and establish a new isolated population on a remote island, carrying only a small, non-representative subset of the mainland population's alleles. What is this phenomenon called, and which evolutionary force does it illustrate?

Lời giải chi tiết

This is the **founder effect** — a special case of **genetic drift** in which a new population is established by a small number of individuals whose allele frequencies (by chance) differ from the source population, so the new population's gene pool is skewed from the outset, independent of any selective advantage.

Bài tập luyện tập

Grey squirrels are introduced from North America to a region of the UK where only red squirrels previously lived; grey squirrels outcompete red squirrels for food, and interbreeding between the two does not occur, but red squirrel allele frequencies in surviving isolated populations change as gene flow patterns shift. Which Hardy–Weinberg assumption most directly explains why the introduction of a new population into a region can alter local allele frequencies?

(A) No selection

(B) No migration — gene flow moves alleles between populations/regions

(C) Random mating

(D) No mutation

Lời giải chi tiết

Movement of individuals (and their alleles) into or out of a population — **gene flow** — violates the "no migration" Hardy–Weinberg assumption and directly changes local allele frequencies. **(B)**.

Bài tập luyện tập

The forelimb of a human, the wing of a bat, and the flipper of a whale all share the same underlying bone arrangement (one proximal bone, two distal bones, then wrist/hand bones), despite performing very different functions. What term describes these structures, and what do they provide evidence for?

(A) Analogous structures; evidence of convergent evolution only

(B) Homologous structures; evidence of common ancestry (divergent evolution from a shared ancestral vertebrate limb plan)

(C) Vestigial structures; evidence of no evolutionary relationship

(D) Homologous structures; evidence that all vertebrates are the same species

Lời giải chi tiết

Structures with the same underlying anatomical plan but different functions across different species are **homologous structures**, inherited (and subsequently modified) from a shared ancestor — strong evidence of **common ancestry**. **(B)**.

Bài tập luyện tập

Explain why molecular (DNA/protein sequence) evidence is often considered more reliable than comparative anatomy alone when establishing evolutionary relationships between two superficially similar species.

Lời giải chi tiết

Superficial anatomical similarity can arise through **convergent evolution** — unrelated species independently evolving similar structures/appearances under similar environmental/selective pressures (analogous structures) — which can mislead a classification based on appearance alone. DNA and protein sequences, by contrast, accumulate differences roughly with time since divergence from a common ancestor regardless of external appearance, so a high percentage sequence similarity is a more direct, quantitative measure of recent common ancestry, less confounded by convergent adaptation to similar niches.

Bài tập luyện tập

Peter and Rosemary Grant's multi-decade study of Galápagos finches recorded a measurable increase in average beak depth in a finch population following a severe drought that left mainly large, hard seeds available. Which type of evidence for evolution does this represent, and which pattern of selection is illustrated?

(A) Fossil evidence; stabilising selection

(B) Direct observation of evolution occurring in real time; directional selection

(C) Molecular evidence; disruptive selection

(D) Comparative anatomy; no selection occurred

Lời giải chi tiết

A measured shift in a population's average phenotype, tracked across real, observed generations, is **direct observation** of evolution in action. Because only the large-beak extreme (better able to crack the remaining hard seeds) was favoured, shifting the population mean toward larger beak depth, this is **directional selection**. **(B)**.

Bài tập luyện tập

Explain what "older rock strata contain progressively different fossils" tells us, and name the geological principle that lets us date fossils by their position in rock layers.

Lời giải chi tiết

Fossils found in progressively deeper (older) rock strata are typically simpler and/or more different from present-day organisms, while shallower (younger) strata show a gradual trend toward modern forms — direct physical evidence that species have changed cumulatively over geological time (e.g. the sequence of fossils in the horse lineage). This dating relies on the **principle of superposition**: in an undisturbed sequence of sedimentary rock layers, older layers lie beneath younger layers.

Bài tập luyện tập

A student claims: "A giraffe stretched its neck reaching for high leaves during its lifetime, and its offspring were born with longer necks as a result." Identify the error in this statement using

natural selection theory.

Lời giải chi tiết

This is a Lamarckian claim (inheritance of acquired characteristics), which is incorrect. Stretching a neck during an individual's lifetime does not change that individual's DNA/alleles, so it cannot be passed to offspring. The correct (Darwinian) explanation is that heritable variation in neck length *already existed* in the ancestral giraffe population (from mutation and recombination); individuals with longer necks (an inherited trait) could reach more/higher food and so survived and reproduced more successfully, passing the allele(s) for longer necks to more offspring — over many generations, the population's average neck length increased through **natural selection**, not through use/disuse within a single lifetime.

Bài tập luyện tập

A biologist proposes classifying two nocturnal mammal species as very closely related because both have large eyes and a similar body shape adapted for gliding. DNA sequence comparison, however, shows the two species' genomes differ substantially more than either does from several other, morphologically quite different, mammal species. What does this most likely indicate, and what classification approach should take priority?

Lời giải chi tiết

This is most likely an example of **convergent evolution**: unrelated (or only distantly related) lineages independently evolving similar features (large eyes, gliding-adapted body shape) in response to a similar ecological niche (nocturnal gliding), producing **analogous**, not homologous, structures. Because molecular (DNA sequence) data reflect actual evolutionary descent far more reliably than superficial physical resemblance, the **molecular/phylogenetic classification** (based on DNA sequence similarity) should take priority over classification by physical appearance alone.

Part B --- Biodiversity, Classification and Conservation

13.9 Defining biodiversity

Three levels of biodiversity

Genetic diversity: the variety of alleles/genes present within a single species (e.g. the range of coat-colour alleles in a wolf population, or the many traditional varieties of rice, *Oryza sativa*, cultivated across Asia). Higher genetic diversity gives a species/population greater capacity to adapt to future environmental change. **Species diversity**: the variety and relative abundance of different species living within a community or ecosystem — itself made up of **species richness** (how many different species are present) and **species evenness** (how evenly individuals are distributed among those species). **Ecosystem (habitat) diversity**: the variety of different habitats/ecosystems present within a region (e.g. a single stretch of coastline may include rocky shore, sand dune, salt marsh and mudflat habitats, each supporting a different community).

VN **GIẢI THÍCH TIẾNG VIỆT**

Ba cấp độ đa dạng sinh học: **đa dạng di truyền** (số alen/gen khác nhau trong một loài — quyết định khả năng thích nghi tương lai), **đa dạng loài** (số lượng và độ phong phú tương đối của các loài trong một quần xã — gồm **độ phong phú loài** và **độ đồng đều loài**), và **đa dạng hệ sinh thái/sinh cảnh** (số loại môi trường sống khác nhau trong một vùng).

13.10 Principles of classification

Organisms are classified into a nested **taxonomic hierarchy** of decreasing group size and increasing similarity between members.

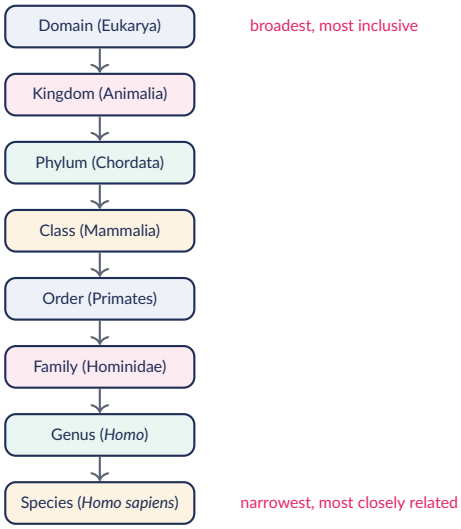

Figure 13.4 — The taxonomic hierarchy, domain to species, worked for *Homo sapiens*.

Ví dụ mẫu — classifying Homo sapiens

Give the full taxonomic classification of the modern human, from domain to species.

Domain **Eukarya** (cells contain a true, membrane-bound nucleus) → Kingdom **Animalia** (multicellular, heterotrophic, no cell wall) → Phylum **Chordata** (possesses a notochord/dorsal nerve cord at some life stage) → Class **Mammalia** (hair, mammary glands, endothermic) → Order **Primates** (grasping hands, forward-facing eyes, large brain relative to body size) → Family **Hominidae** (great apes) → Genus ***Homo*** → Species ***sapiens***. The full binomial scientific name is *Homo sapiens*.

Binomial nomenclature

Every species is given a unique two-part scientific name: *Genus species* — the **genus** name is capitalised, the **species (specific) epithet** is lower-case, and both are italicised (or underlined if handwritten), e.g. *Panthera leo* (lion). This system, devised by Linnaeus, gives every organism a single, universal name recognised worldwide, avoiding the confusion caused by common names that vary between languages, countries, and even regions of the same country (e.g. ”corn” means maize in the USA but wheat/cereal crops generally in the UK).

VN **GIẢI THÍCH TIẾNG VIỆT**

Hệ thống phân loại theo bậc từ rộng đến hẹp: giới vực (domain) → giới (kingdom) → ngành (phylum) → lớp (class) → bộ (order) → họ (family) → chi/giống (genus) → loài (species). **Danh pháp hai phần**: Tên chi viết hoa + tên loài viết thường, in nghiêng (VD: *Homo sapiens*) — giúp

thống nhất tên gọi khoa học toàn cầu, tránh nhầm lẫn do tên thông thường khác nhau giữa các ngôn ngữ/vùng miền.

13.11 The three-domain system and the five-kingdom system

	Three-domain system (Woese, molecular)	**Five-kingdom system** (Whittaker, structural)
Top-level groups	**Bacteria**, **Archaea**, **Eukarya**	Prokaryotae (Monera), Protoctista, Fungi, Plantae, Animalia
Basis of grouping	Molecular evidence — rRNA/DNA sequence comparison, cell membrane lipid chemistry, cell wall biochemistry	Cell structure (prokaryotic/eukaryotic), mode of nutrition, level of organisation
Key insight	The two prokaryotic groups (Bacteria and Archaea) are, at the molecular level, as different from each other as either is from Eukarya, despite looking structurally similar	Treats all prokaryotes as a single kingdom (Monera), since molecular differences between Bacteria and Archaea were not yet known
Relationship	The old Prokaryotae/Monera kingdom is split into domains Bacteria and Archaea; the four remaining eukaryotic kingdoms (Protoctista, Fungi, Plantae, Animalia) all sit within domain Eukarya	Superseded (for phylogenetic purposes) by the three-domain system, though still used informally to describe major eukaryotic groups

Table 13.2 — Three-domain system versus five-kingdom system.

Archaea are structurally prokaryotic (no nucleus, no membrane-bound organelles) and were originally classified with Bacteria, but molecular evidence (distinctive rRNA sequences, different membrane lipids, different cell wall chemistry) shows they are genetically highly distinct from Bacteria — in some respects more similar to Eukarya (e.g. some aspects of their transcription/translation machinery). Archaea are often found in extreme environments (hot springs, salt lakes, anaerobic sediments), though many also live in ordinary habitats.

VN **GIẢI THÍCH TIẾNG VIỆT**

Hệ **ba lãnh giới** (Bacteria, Archaea, Eukarya) dựa trên bằng chứng phân tử (so sánh trình tự rRNA/DNA), cho thấy Bacteria và Archaea khác biệt sâu sắc về mặt di truyền dù cùng là sinh vật nhân sơ về cấu trúc. Hệ **năm giới** cũ (Monera, Protoctista, Fungi, Plantae, Animalia) chỉ dựa trên cấu trúc tế bào và dinh dưỡng, gộp chung Bacteria và Archaea vào một giới Monera.

13.12 Phylogenetic classification

Phylogenetic classification groups organisms according to their **evolutionary relatedness** (how recently they shared a common ancestor), increasingly using molecular (DNA/rRNA/protein sequence) data alongside traditional morphological comparison, since molecular data are less easily confounded by convergent evolution.

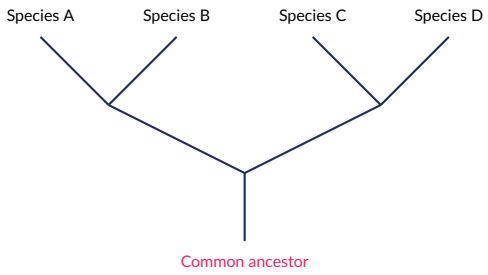

Figure 13.5 — A phylogenetic tree. Branch points represent common ancestors; species sharing a more recent common ancestor (A and B) are more closely related than species separated by an earlier branch point (A and D, via the earliest common ancestor).

Ví dụ mẫu — convergent evolution and classification

A shark (a cartilaginous fish) and a dolphin (a mammal) have very similar external body shapes: streamlined bodies, a dorsal fin, and paired pectoral fins/flippers. Explain why classifying them together based on this external similarity would be incorrect, and what evidence correctly separates them.

Both species independently evolved a similar streamlined body shape because both live in, and are adapted for fast movement through, the same physical medium (water) — this is **convergent evolution**, producing **analogous** structures (similar function/appearance, different evolutionary origin), not evidence of a recent common ancestor. Internal anatomy (sharks have a cartilaginous skeleton, gills, and no mammary glands; dolphins have a bony skeleton, lungs, mammary glands and hair) and, most decisively, **molecular/DNA sequence data** correctly place them in very different, distantly-related phylogenetic groups (Chondrichthyes vs. Mammalia) despite their superficial resemblance.

13.13 Measuring biodiversity: richness, evenness and Simpson's Index

Richness vs. evenness

Species richness is simply the number of different species present in a sample or habitat (a count). **Species evenness** describes how evenly individuals are distributed among those species (relative abundance) — a community can have high richness but low evenness if one species numerically dominates while the others are all rare.

Ví dụ mẫu — richness vs. evenness with equal richness

Two habitat samples each contain exactly 4 species and 100 individuals in total. Community X: $25, 25, 25, 25$. Community Y: $91, 3, 3, 3$. Calculate Simpson's Index of Diversity, $D = 1 - \sum(n/N)^2$, for each, and comment.

Community X: $\sum(n/N)^2 = 4 \times (0.25)^2 = 4 \times 0.0625 = 0.25$. $D_X = 1 - 0.25 =$ **0.75**.

Community Y: $\sum(n/N)^2 = (0.91)^2 + 3 \times (0.03)^2 = 0.8281 + 0.0027 = 0.8308$. $D_Y = 1 - 0.8308 =$ **0.169**.

Both communities have identical species **richness** (4 species), yet Community X ($D = 0.75$) is far more diverse than Community Y ($D \approx 0.17$), because X has much higher **evenness** — individuals are spread equally among the four species, whereas in Y a single dominant species accounts for 91% of individuals. This shows that richness alone is a poor measure of true diversity; Simpson's Index captures both richness and evenness together.

Simpson's Index of Diversity

$$D = 1 - \sum \left(\frac{n}{N}\right)^2$$

where n = number of individuals of one particular species, and N = total number of individuals of *all* species in the sample. D ranges from 0 (minimum diversity — theoretically, only one species present) up to just under 1 (very high diversity — many species, evenly represented). The closer D is to 1, the more diverse the community.

Species	**Count,** n	$(n/N)^2$
Species 1	15	$(0.30)^2 = 0.0900$
Species 2	12	$(0.24)^2 = 0.0576$
Species 3	10	$(0.20)^2 = 0.0400$
Species 4	8	$(0.16)^2 = 0.0256$
Species 5	5	$(0.10)^2 = 0.0100$
Total $N = 50$		$\sum(n/N)^2 = 0.2232$

Table 13.3 — Worked Simpson's Index data: woodland leaf-litter invertebrate survey.

Ví dụ mẫu — Simpson's Index, woodland leaf-litter survey

A leaf-litter survey (Table 13.3) records 5 invertebrate species with counts $15, 12, 10, 8, 5$ (total $N = 50$). Calculate Simpson's Index of Diversity.

Proportions: $n/N = 0.30,\ 0.24,\ 0.20,\ 0.16,\ 0.10$. Squares: $0.0900,\ 0.0576,\ 0.0400,\ 0.0256,\ 0.0100$. Sum $= 0.0900 + 0.0576 + 0.0400 + 0.0256 + 0.0100 = 0.2232$. $D = 1 - 0.2232 =$ **0.777** — a relatively high-diversity community, with individuals fairly evenly spread across five species.

Ví dụ mẫu — Simpson's Index, dominated field-margin survey

A second survey, of an arable field margin, records 5 plant species with counts $90, 4, 3, 2, 1$ (total $N = 100$). Calculate Simpson's Index of Diversity and compare with the woodland result above.

Proportions: $0.90,\ 0.04,\ 0.03,\ 0.02,\ 0.01$. Squares: $0.8100,\ 0.0016,\ 0.0009,\ 0.0004,\ 0.0001$. Sum $= 0.8100 + 0.0016 + 0.0009 + 0.0004 + 0.0001 = 0.8130$. $D = 1 - 0.8130 =$ **0.187**. Despite having the same number of species categories as the woodland survey, this community is far **less diverse** ($D \approx 0.19$ vs. 0.78), because one species (accounting for 90% of individuals) dominates almost completely — low evenness drives D down even when richness is unchanged.

(!) Lỗi thường gặp: Always convert each species' count to a **proportion** (n/N) and **square it** before summing — a common error is to sum the raw counts, or to forget the final "$1 -$" step (giving $\sum(n/N)^2$ instead of D itself, which has the opposite trend: it is *large* for low-diversity, dominated communities).

VN **GIẢI THÍCH TIẾNG VIỆT**

Chỉ số đa dạng Simpson $D = 1 - \sum(n/N)^2$: n là số cá thể của một loài, N là tổng số cá thể tất cả các loài. D càng gần 1, quần xã càng đa dạng (nhiều loài, phân bố đều); D càng gần 0, quần xã càng kém đa dạng (một loài chiếm ưu thế áp đảo). Lưu ý: phải tính tỉ lệ n/N rồi **bình**

phương từng loài trước khi cộng lại, và không quên bước "$1 -$ " ở cuối.

13.14 Sampling techniques: quadrats and transects

Random quadrats

Used to estimate the abundance/percentage cover of relatively immobile (sessile) organisms, especially plants, within a habitat. A grid of coordinates is marked across the study area (e.g. using two long tape measures at right angles); coordinates are then generated using a **random number generator** (calculator, app, or random number table) — *not* chosen by eye — to avoid unconscious bias (e.g. a surveyor unconsciously placing quadrats where a species "looks" abundant). A quadrat frame of known area (e.g. $0.5\,\text{m} \times 0.5\,\text{m} = 0.25\,\text{m}^2$) is placed at each randomly generated coordinate, and the number of individuals (or percentage cover, for e.g. grasses/mosses) of each species present is recorded. A sufficiently large number of quadrats (commonly ≥ 10–20) are sampled to obtain a reliable mean.

Belt and line transects

Used to investigate how species distribution/abundance changes along an environmental **gradient** (e.g. zonation up a rocky shore from the low-tide to the high-tide mark, or across the boundary from woodland into open grassland). A tape measure is laid along the gradient. A **line transect** simply records which species touch the tape at set intervals (presence/absence data only). A **belt transect** places quadrats (contiguously, or at regular intervals) along the tape, giving quantitative abundance/percentage-cover data for every species at each point along the gradient — allowing a clearer picture of how each species' abundance changes with position (e.g. with distance from the sea, or height up the shore).

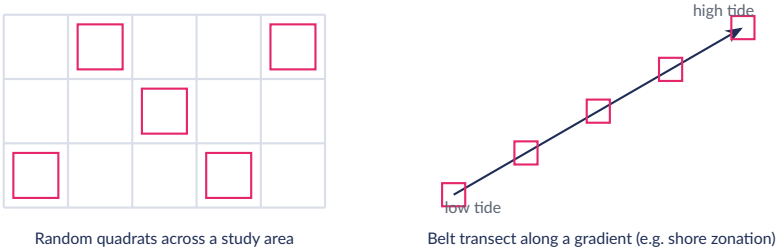

Figure 13.6 — Random quadrat sampling (left) versus a belt transect along an environmental gradient (right).

Ví dụ mẫu — estimating total population size from quadrat data

A student records the number of dandelion plants in 20 randomly-placed quadrats, each of area $0.25\,\text{m}^2$, in a field of total area $500\,\text{m}^2$. The mean count is 6 dandelions per quadrat. Estimate the total dandelion population in the field.

Density $= \dfrac{\text{mean count per quadrat}}{\text{quadrat area}} = \dfrac{6}{0.25} = 24$ dandelions per m^2. Estimated total population $=$ density $\times$ total area $= 24 \times 500 =$ **12 000** dandelions.

Ví dụ mẫu — interpreting belt transect zonation data

A belt transect run from the low-tide to the high-tide mark on a rocky shore records: oarweed (kelp) abundant only in the lowest 2 m nearest the sea; bladder wrack abundant in the middle

zone; channelled wrack abundant only in the top 2 m nearest the high-tide mark; barnacles present in a broad band overlapping the middle and upper zones. Suggest an explanation for this pattern of zonation.

This distribution reflects a gradient in **exposure to air, desiccation (drying out) and temperature extremes** with height up the shore: the lowest zone is submerged most of the time (least desiccation stress), suiting less desiccation-tolerant species like oarweed; the highest zone is exposed to air for the longest time each tidal cycle (greatest desiccation/temperature stress), which only the most desiccation-tolerant species (e.g. channelled wrack, with a thick waxy cuticle and ability to lose a high percentage of body water) can survive. The overlapping barnacle band reflects a species with an intermediate tolerance range and/or competitive interactions with the algae.

VN **GIẢI THÍCH TIẾNG VIỆT**

Ô mẫu ngẫu nhiên (quadrat): dùng để ước lượng độ phong phú/độ che phủ của sinh vật ít di chuyển (thường là thực vật); toạ độ đặt ô mẫu phải được tạo bằng **số ngẫu nhiên** để tránh thiên lệch chủ quan. **Tuyến cắt (transect)**: dùng để khảo sát sự thay đổi phân bố loài dọc theo một **gradient** môi trường (VD: phân đới trên bờ biển) — tuyến cắt dạng dải (belt transect) đặt các ô mẫu liên tiếp dọc tuyến để thu số liệu định lượng, trong khi tuyến cắt đường (line transect) chỉ ghi nhận có/không có loài chạm vào dây.

13.15 Threats to biodiversity

Habitat loss and fragmentation: agriculture, logging and urbanisation destroy habitat outright and split remaining habitat into small, isolated fragments, reducing population sizes and gene flow between them and increasing vulnerable "edge" habitat. **Climate change**: shifting temperature/rainfall patterns can shrink or shift a species' suitable range faster than it can migrate or adapt, and cause mismatches in timing between species (e.g. flowering time vs. pollinator activity); rising sea temperature/acidity drives coral bleaching. **Pollution**: chemical, plastic and agricultural runoff (fertiliser-driven eutrophication, pesticide bioaccumulation) degrades habitat quality and directly poisons organisms. **Overexploitation**: harvesting (overfishing, poaching, unsustainable logging) faster than a population can naturally replace itself drives population decline and, ultimately, extinction. **Invasive species**: species introduced (deliberately or accidentally) to a new region, often lacking natural predators/competitors there, can outcompete, prey on, or hybridise with native species, disrupting the existing community.

VN **GIẢI THÍCH TIẾNG VIỆT**

Các mối đe doạ chính đến đa dạng sinh học: **mất/chia cắt sinh cảnh** (nông nghiệp, đô thị hoá, khai thác gỗ), **biến đổi khí hậu** (thay đổi nhiệt độ/lượng mưa nhanh hơn khả năng thích nghi), **ô nhiễm** (hoá chất, nhựa, nước thải nông nghiệp gây phú dưỡng), **khai thác quá mức** (đánh bắt/săn bắt vượt quá khả năng phục hồi tự nhiên), và **loài xâm lấn** (không có thiên địch tự nhiên ở vùng mới, cạnh tranh/ăn thịt/lai với loài bản địa).

13.16 Conservation strategies: in-situ and ex-situ

	In-situ conservation	Ex-situ conservation
Definition	Protecting species within their natural habitat	Protecting species/genetic material outside their natural habitat
Examples	National parks, marine protected areas, wildlife corridors (connect fragmented habitats, restore gene flow), habitat management (controlled grazing/fire, invasive species removal)	Captive breeding programmes (zoos, with studbooks to manage genetic diversity), seed banks, botanic gardens, cryopreservation of gametes/embryos
Advantages	Preserves natural behaviour and co-evolved ecological interactions (predator–prey, pollination, symbiosis); generally more cost-effective at protecting whole communities/ecosystems at once	Protects critically small populations from immediate extinction; allows carefully managed breeding to avoid inbreeding; can preserve genetic material indefinitely (cryopreservation, seed banks)
Limitations	Vulnerable to habitat-wide threats (disease outbreak, natural disaster, ongoing climate change, poaching); requires long-term political/international cooperation and enforcement; land-use conflicts with human development	Does not preserve natural habitat, behaviour or ecological interactions; expensive and resource-intensive; captive populations risk losing genetic diversity or becoming adapted to captivity; reintroduction to the wild is often difficult

Table 13.4 — In-situ versus ex-situ conservation.

International conservation agreements

CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora) is an international agreement that restricts or bans international trade in endangered species and products derived from them (e.g. ivory, certain timbers, exotic pets), directly targeting overexploitation driven by trade. The **IUCN Red List** assesses and publishes the conservation status of species (e.g. Vulnerable, Endangered, Critically Endangered) to guide conservation priorities, and the **Convention on Biological Diversity** is a broader international treaty committing signatory countries to conserve biodiversity, use its components sustainably, and share the benefits of genetic resources fairly.

Ví dụ mẫu — classifying conservation strategies

Classify each of the following as in-situ or ex-situ conservation, and justify each answer: (a) A wildlife corridor of replanted forest connecting two previously isolated nature reserves. (b) A national seed bank storing seeds from wild relatives of wheat at $-20\,^{\circ}$C. (c) A marine protected area banning trawling within its boundaries.

(a) **In-situ**: the corridor keeps species within (an extension of) their natural habitat, restoring

gene flow between reserves rather than removing organisms from the wild.
(b) **Ex-situ**: seeds are removed from their natural habitat and stored artificially, preserving genetic material outside the wild population.
(c) **In-situ**: the species remain in their natural marine habitat; the protection is achieved by restricting a human activity (trawling) within that habitat.

VN **GIẢI THÍCH TIẾNG VIỆT**

Bảo tồn **tại chỗ (in-situ)**: bảo vệ loài ngay trong môi trường sống tự nhiên (vườn quốc gia, khu bảo tồn biển, hành lang sinh thái nối các sinh cảnh bị chia cắt) — giữ được tập tính tự nhiên và các mối quan hệ sinh thái, nhưng dễ bị tổn thương trước các mối đe doạ trên toàn sinh cảnh. Bảo tồn **chuyển vị (ex-situ)**: đưa cá thể/vật liệu di truyền ra khỏi môi trường tự nhiên để bảo vệ (nhân giống nuôi nhốt, ngân hàng hạt giống, vườn thực vật, đông lạnh giao tử/phôi) — hữu ích khi quần thể đã quá nhỏ, nhưng tốn kém và không giữ được tập tính/mối quan hệ sinh thái tự nhiên. **CITES** là hiệp ước quốc tế hạn chế buôn bán các loài nguy cấp.

Part B --- Practice

Bài tập luyện tập

Which level of biodiversity is illustrated by the existence of many different alleles for coat colour within a single wolf population?

(A) Ecosystem diversity
(B) Species diversity
(C) Genetic diversity
(D) Taxonomic diversity

Lời giải chi tiết

Variation in alleles *within one species* is the definition of **genetic diversity**. **(C)**.

Bài tập luyện tập

A coastline contains rocky shore, sand dune, salt marsh, and mudflat habitats, each supporting a different community of organisms. Which level of biodiversity does this illustrate?

(A) Genetic diversity
(B) Ecosystem (habitat) diversity
(C) Species evenness only
(D) None; this is not a recognised level of biodiversity

Lời giải chi tiết

The variety of different types of habitat/ecosystem within a region defines **ecosystem (habitat) diversity**. **(B)**.

Bài tập luyện tập

Arrange the following taxonomic ranks in order from broadest to narrowest: Family, Species, Class, Domain, Order, Kingdom, Phylum, Genus.

Lời giải chi tiết

Domain → Kingdom → Phylum → Class → Order → Family → Genus → Species.

Bài tập luyện tập

Which of these is correctly written according to the rules of binomial nomenclature?

(A) *panthera Leo*
(B) *Panthera Leo*
(C) *Panthera leo*
(D) PANTHERA LEO

Lời giải chi tiết

The genus is capitalised, the species epithet is lower-case, and both are italicised: *Panthera leo*. **(C)**.

Bài tập luyện tập

Explain why binomial nomenclature (rather than relying on common names) is essential for international scientific communication.

Lời giải chi tiết

Common names vary between languages, countries and even regions of the same country, and the same common name can refer to different organisms in different places (or the same organism can have many different common names). A unique, universally-agreed two-part Latinised scientific name (genus + species) removes this ambiguity, allowing scientists anywhere in the world to be certain they are discussing exactly the same organism.

Bài tập luyện tập

Which three groups make up the modern three-domain system of classification?

(A) Monera, Protoctista, Animalia
(B) Bacteria, Archaea, Eukarya
(C) Plantae, Fungi, Animalia
(D) Prokaryotae, Protoctista, Eukarya

Lời giải chi tiết

The three domains are **Bacteria**, **Archaea** and **Eukarya**. **(B)**.

Bài tập luyện tập

Explain why the discovery of molecular (rRNA sequence) differences between Bacteria and Archaea led to the replacement of the old single "Monera" kingdom with two separate domains.

Lời giải chi tiết

Under the five-kingdom system, all prokaryotes (structurally: no nucleus, no membrane-bound organelles) were grouped together as Monera/Prokaryotae, based purely on cell structure. Once rRNA and other molecular sequence comparisons became possible, they revealed that Bacteria and Archaea are genetically as different from one another as either is from Eukarya,

despite their shared prokaryotic cell structure — a deep evolutionary split that a purely structural classification could not detect. This molecular evidence justified splitting the old single prokaryotic kingdom into two separate domains.

Bài tập luyện tập

On a phylogenetic tree, species A and species B share a more recent common ancestor (branch point) than either does with species C. What can be concluded?

(A) Species A and B are more closely related to each other than either is to species C

(B) Species A, B and C are equally related

(C) Species C must be extinct

(D) No conclusion about relatedness can be drawn from a phylogenetic tree

Lời giải chi tiết

The more recently two branches diverge from a shared node (common ancestor), the more closely related the two corresponding species are. **(A)**.

Bài tập luyện tập

Two beetle species look almost identical (similar colour, size and shape) but occupy very different branches on a molecular phylogenetic tree, while each is closely related to visually quite different beetle species on its own branch. What does this most likely indicate?

Lời giải chi tiết

This most likely indicates **convergent evolution**: the two similar-looking beetles independently evolved similar external features (perhaps under similar selective pressures, e.g. camouflage or mimicry), producing **analogous** structures, while their true evolutionary relationships (revealed by molecular data) lie with their own, morphologically different, close relatives. This illustrates why molecular/phylogenetic classification is more reliable than classification by appearance alone.

Bài tập luyện tập

Two woodland samples each contain 5 tree species. Sample 1 has 20 individuals of each species ($N = 100$). Sample 2 has $80, 5, 5, 5, 5$ ($N = 100$). Which sample has higher species richness, and which has higher species evenness?

(A) Sample 1 has higher richness and higher evenness

(B) Both have equal richness; Sample 1 has higher evenness

(C) Both have equal richness; Sample 2 has higher evenness

(D) Sample 2 has higher richness; Sample 1 has higher evenness

Lời giải chi tiết

Both samples contain the same number of species (5), so **richness is equal**. Sample 1 distributes individuals perfectly evenly (20 each); Sample 2 is dominated by one species (80%), so **evenness is much higher in Sample 1**. **(B)**.

Bài tập luyện tập

For Sample 1 and Sample 2 in the previous question, calculate Simpson's Index of Diversity for each and confirm which is more diverse overall.

Lời giải chi tiết

Sample 1: $n/N = 0.20$ for each of 5 species; $\sum(n/N)^2 = 5 \times (0.20)^2 = 5 \times 0.04 = 0.20$. $D_1 = 1 - 0.20 = \mathbf{0.80}$.
Sample 2: $\sum(n/N)^2 = (0.80)^2 + 4 \times (0.05)^2 = 0.64 + 0.01 = 0.65$. $D_2 = 1 - 0.65 = \mathbf{0.35}$.
Sample 1 ($D = 0.80$) is substantially more diverse than Sample 2 ($D = 0.35$) despite identical richness, confirming that evenness strongly affects overall diversity as measured by Simpson's Index.

Bài tập luyện tập

A rockpool survey records 4 species of invertebrate with counts $12, 12, 12, 12$ ($N = 48$). Calculate Simpson's Index of Diversity.

(A) $D = 0.25$
(B) $D = 0.50$
(C) $D = 0.75$
(D) $D = 1.00$

Lời giải chi tiết

Each species: $n/N = 12/48 = 0.25$; $(0.25)^2 = 0.0625$. $\sum(n/N)^2 = 4 \times 0.0625 = 0.25$. $D = 1 - 0.25 = \mathbf{0.75}$. **(C)**.

Bài tập luyện tập

A grassland survey records 3 plant species with counts $60, 30, 10$ ($N = 100$). Calculate Simpson's Index of Diversity, showing every step.

Lời giải chi tiết

Proportions: $0.60, 0.30, 0.10$. Squares: $0.36, 0.09, 0.01$. Sum $= 0.36 + 0.09 + 0.01 = 0.46$. $D = 1 - 0.46 = \mathbf{0.54}$.

Bài tập luyện tập

Explain why quadrat sample coordinates must be generated using random numbers rather than being chosen by the surveyor "by eye".

Lời giải chi tiết

If a surveyor chooses quadrat positions by eye, they may unconsciously select locations that look particularly rich or particularly sparse in a species of interest, systematically biasing the sample away from a true representative average. Generating coordinates using a random number generator (or random number table) ensures every point in the sampling grid has an equal chance of being selected, so the resulting sample gives an unbiased estimate of abundance/percentage cover across the whole study area.

Bài tập luyện tập

A student samples 15 quadrats, each $1\,\text{m}^2$, in a $2000\,\text{m}^2$ field and finds a mean of 9 buttercup plants per quadrat. Estimate the total buttercup population in the field.

(A) $9\,000$
(C) $2\,000$
(B) $18\,000$
(D) 135

Lời giải chi tiết

Density $= 9$ plants per m^2 (since the quadrat area is $1\,\text{m}^2$). Estimated total $=$ density $\times$ total area $= 9 \times 2000 =$ **18 000**. **(B)**.

Bài tập luyện tập

A student samples 10 quadrats, each $0.5\,\text{m}^2$, in a meadow of total area $1200\,\text{m}^2$, and finds a mean of 4 orchid plants per quadrat. Estimate the total orchid population, showing your working.

Lời giải chi tiết

Density $= \dfrac{4}{0.5} = 8$ orchids per m^2. Estimated total population $= 8 \times 1200 =$ **9 600** orchids.

Bài tập luyện tập

Explain the key difference between a line transect and a belt transect, and state which would be more appropriate for quantifying how the percentage cover of three algal species changes with height up a rocky shore.

Lời giải chi tiết

A **line transect** records only whether each species touches the tape at set points (presence/absence), giving no abundance data. A **belt transect** places quadrats along the tape, allowing the percentage cover (or count) of every species to be recorded quantitatively at each point. Because the question asks for how *percentage cover changes* (a quantitative measure) with shore height, a **belt transect** is the appropriate method.

Bài tập luyện tập

A belt transect up a rocky shore shows barnacles restricted mainly to the upper and middle shore, while a particular red seaweed is restricted to the lower shore only. Suggest the environmental factor most likely responsible for this zonation pattern.

(A) Wind direction alone
(C) Random chance, with no underlying environmental cause
(B) Gradient in exposure time to air/desiccation stress with tidal height
(D) Predation by birds only

Lời giải chi tiết

Zonation on a rocky shore is chiefly driven by the gradient in **time spent exposed to air** (and associated desiccation, temperature extremes and UV exposure) between the frequently-

submerged lower shore and the rarely-submerged upper shore; species differ in their tolerance of this stress, producing distinct zones. **(B)**.

Bài tập luyện tập

Explain how habitat fragmentation (splitting one large habitat into several small, isolated patches) can reduce a species' long-term genetic diversity, even if total remaining habitat area only shrinks a little.

Lời giải chi tiết

Fragmentation isolates smaller sub-populations from one another, restricting gene flow between them. Each small isolated sub-population is then more vulnerable to genetic drift (random allele frequency changes and loss of rare alleles by chance) and to inbreeding, both of which reduce genetic diversity over time — even if the total remaining habitat area is not drastically smaller than before, the loss of connectivity itself lowers the effective population size of each fragment.

Bài tập luyện tập

Explain how climate change can threaten a species even if the species itself is not directly harmed by warmer temperatures.

Lời giải chi tiết

Climate change can create a "phenological mismatch": for example, if warmer spring temperatures cause a plant to flower earlier, but its pollinator's life cycle (timed by day length rather than temperature) does not shift to match, the plant may no longer be pollinated effectively when it flowers, even though neither species is directly physiologically harmed by the higher temperature itself. Similarly, a species' suitable climatic range may shift geographically faster than the species itself, or the habitats/prey it depends on, can migrate or adapt.

Bài tập luyện tập

An introduced species thrives in a new region partly because none of the native predators there recognise it as prey. Which threat to biodiversity does this best illustrate, and what is the likely effect on native species?

(A) Pollution; native species are poisoned directly

(B) Invasive species; native species may be outcompeted, preyed upon, or hybridised with, disrupting the existing community

(C) Overexploitation; native species are over-harvested by humans

(D) Habitat fragmentation; native habitat is physically split apart

Lời giải chi tiết

An introduced species establishing successfully because it lacks natural enemies in its new range, and subsequently disrupting the native community, is the definition of an **invasive species** threat. **(B)**.

Bài tập luyện tập

Give one named advantage and one named limitation of in-situ conservation, using a wildlife corridor as your example.

Lời giải chi tiết

Advantage: a wildlife corridor restores gene flow and natural movement between two previously fragmented populations, maintaining genetic diversity and natural behaviour/ecological interactions without removing any organisms from the wild. **Limitation**: the corridor and both reserves it connects remain vulnerable to habitat-wide threats such as disease outbreaks, wildfire, or continued encroachment by human land use, and establishing the corridor typically requires long-term political cooperation/land-use agreement across multiple landowners or jurisdictions.

Bài tập luyện tập

A conservation programme freezes sperm and egg cells from a critically endangered species in liquid nitrogen for possible future use. State the term for this method and one limitation of relying on it as a conservation strategy.

(A) In-situ conservation; it destroys the species' natural habitat

(B) Ex-situ conservation (cryopreservation); it does not preserve the species' natural habitat or wild population, and future assisted-reproduction techniques may not always succeed

(C) This is not a recognised conservation method

(D) In-situ conservation; it requires no further intervention

Lời giải chi tiết

Freezing gametes for long-term storage away from the wild population is **ex-situ conservation (cryopreservation)**. A key limitation is that it preserves genetic material only, not the species' natural habitat, ecological relationships, or learned behaviours, and successfully using the stored material to re-establish a healthy wild population later depends on assisted-reproduction/reintroduction techniques that are not always reliable. **(B)**.

Bài tập luyện tập

State the purpose of CITES, and explain how it addresses one specific threat to biodiversity.

Lời giải chi tiết

CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora) is an international agreement that restricts or bans cross-border trade in endangered species and products derived from them. It directly addresses **overexploitation**: by making international trade in listed species illegal or tightly controlled, it reduces the economic incentive to overharvest/poach those species for export markets (e.g. ivory, exotic pet trade, certain timbers).

Bài tập luyện tập

A national park protects an entire ecosystem, including all its species and their natural interactions, but a nearby wildfire (intensified by drought) burns a large portion of it in a single season. Which limitation of in-situ conservation does this best illustrate?

Lời giải chi tiết

This illustrates that in-situ conservation, while preserving natural habitat and ecological interactions under normal conditions, remains **vulnerable to habitat-wide threats** (natural disasters, disease outbreaks, or climate-change-intensified events like drought and wildfire) that can damage or destroy the entire protected area at once — a risk that a dispersed ex-situ genetic reserve (e.g. a seed bank or captive breeding population held elsewhere) would not share.

Genetic Technology

A2 Level

Mục tiêu Unit: Nguyên lý công nghệ DNA tái tổ hợp; thu nhận đoạn DNA (enzyme cắt giới hạn, phiên mã ngược); PCR (cơ chế và tính toán số bản sao); điện di gel và ứng dụng pháp y; nhân dòng gen (plasmid, DNA ligase, biến nạp, sàng lọc xanh/trắng); sinh vật biến đổi gen; liệu pháp gen soma và mầm; sàng lọc và tư vấn di truyền (đầu dò DNA, lai phân tử); công nghệ chỉnh sửa gen CRISPR–Cas9.

14.1 Recombinant DNA technology: general principle

The general strategy

Recombinant DNA technology follows the same broad strategy whatever the target gene or host organism: (1) **isolate or synthesise** the gene of interest; (2) **insert** that gene into a **vector** (commonly a bacterial plasmid or a viral genome) to form a **recombinant** DNA molecule; (3) introduce the recombinant vector into a **host cell/organism** (**transformation**); (4) **select** for host cells that have successfully taken up the gene, and allow them to express it (e.g. to mass-produce a protein) or to pass the new gene on (e.g. in a genetically modified crop).

VN **GIẢI THÍCH TIẾNG VIỆT**

Công nghệ DNA tái tổ hợp gồm 4 bước chung: (1) phân lập/tổng hợp gen mong muốn; (2) gắn gen đó vào một **vector** (thường là plasmid vi khuẩn) tạo DNA tái tổ hợp; (3) đưa vector tái tổ hợp vào tế bào chủ (**biến nạp**); (4) chọn lọc những tế bào chủ đã nhận thành công gen mới và biểu hiện nó.

14.2 Obtaining a gene of interest

Restriction endonucleases

Restriction endonucleases are bacterial enzymes (part of a bacterium's natural defence against invading viral DNA) that recognise a specific, short, **palindromic recognition sequence** (one that reads the same on both strands in the $5' \rightarrow 3'$ direction, e.g. `GAATTC`) and cut the DNA backbone at, or near, that sequence. Some restriction enzymes cut straight across both strands at the same point, leaving **blunt ends**; many cut the two strands at slightly offset positions, leaving short, single-stranded, complementary overhangs called **sticky (cohesive) ends**. Sticky ends are especially useful in recombinant DNA technology because the single-stranded overhang can **base-pair (anneal)** with any other DNA fragment cut by the *same* restriction enzyme (since it leaves the identical complementary overhang), allowing a gene of interest and a vector to be joined together reliably even though they came from different sources.

Reverse transcriptase

Reverse transcriptase, an enzyme derived from retroviruses, synthesises a single strand of **complementary DNA (cDNA)** using an **mRNA** template (the reverse of normal transcription). A second strand is then synthesised (using DNA polymerase) to give double-stranded cDNA. Because mature eukaryotic mRNA has already had its **introns removed** by splicing, cDNA made from it is an **intron-free** copy of the gene — essential when inserting a eukaryotic gene into a bacterial host, since bacteria lack the spliceosome machinery needed to remove introns and would otherwise produce a non-functional (or truncated) protein from an intron-containing gene.

Two distinct routes to obtain a gene of interest: **cutting it directly out of genomic DNA** using restriction enzymes (works well for genes with no introns, e.g. most bacterial genes), or **synthesising an intron-free cDNA copy** from mature mRNA using reverse transcriptase (essential for expressing eukaryotic genes, which contain introns, in a bacterial host).

VN **GIẢI THÍCH TIẾNG VIỆT**

Enzyme cắt giới hạn nhận biết một trình tự đối xứng ngắn (palindromic) đặc hiệu và cắt DNA tại đó, tạo đầu bằng (blunt end) hoặc đầu dính (sticky end, có đoạn mạch đơn thừa ra) — đầu dính đặc biệt hữu ích vì có thể bắt cặp bổ sung với bất kỳ đoạn DNA nào khác được cắt bởi **cùng loại enzyme**. **Enzyme phiên mã ngược** tổng hợp cDNA từ khuôn mRNA — vì mRNA trưởng thành đã loại bỏ intron, cDNA thu được **không chứa intron**, rất cần thiết khi biểu hiện gen sinh vật nhân thực (có intron) trong vi khuẩn (không có bộ máy cắt intron).

14.3 The polymerase chain reaction (PCR)

PCR amplifies a specific target DNA sequence exponentially *in vitro*, without needing a living cell, through repeated temperature cycles.

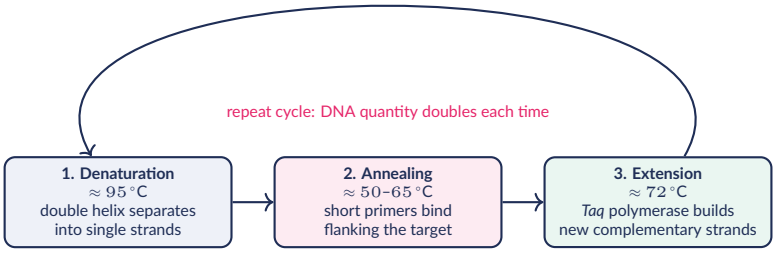

Figure 14.1 — The three-step PCR cycle, repeated 20–40 times.

The three PCR steps, in detail

Denaturation ($\approx 95\,^{\circ}$C): heating breaks the hydrogen bonds holding the two DNA strands together, separating the double helix into two single strands, each available as a template. **Annealing** (≈ 50–$65\,^{\circ}$C, the reaction is cooled): short, single-stranded **primers** (synthetic oligonucleotides, complementary to sequences immediately flanking the target region on each strand) bind (anneal) to their complementary sequences, marking the start point for new strand synthesis and defining exactly which region will be amplified. **Extension** ($\approx 72\,^{\circ}$C): a heat-stable DNA polymerase, ***Taq* polymerase** (isolated from *Thermus aquaticus*, a bacterium living in hot springs), extends each primer, synthesising a new complementary strand using free nucleotides in the reaction mixture.

(!) Lỗi thường gặp: An ordinary human/mammalian DNA polymerase would be **denatured (permanently destroyed)** by the repeated $95\,^{\circ}$C heating step and would have to be added fresh every single cycle. *Taq* polymerase, from a bacterium naturally adapted to hot springs, remains stable and functional even after being heated to $95\,^{\circ}$C many times in succession — this heat tolerance is precisely why PCR became a practical, automatable technique (a single addition of *Taq* polymerase works for the entire, many-cycle reaction).

Exponential amplification

Because each of the two strands produced in one cycle serves as a template in the next cycle, the number of target DNA molecules approximately **doubles with every cycle**: after n cycles, starting from a single target molecule, there are approximately 2^n copies. Starting from N_0 initial target molecules, after n cycles there are approximately $N_0 \times 2^n$ copies. This is why even a trace amount of starting DNA (e.g. from a single hair root, or a small forensic sample) can be amplified to a quantity large enough to analyse within a couple of hours.

Ví dụ mẫu — PCR exponential amplification, small cycle number

A PCR reaction begins with a single target DNA molecule. Calculate the number of copies present after 10 cycles, assuming perfect doubling each cycle.
$N = 1 \times 2^{10} =$ **1 024** molecules.

Ví dụ mẫu — PCR exponential amplification, forensic-scale cycle number

A forensic sample yields 8 copies of a target DNA sequence. After 20 PCR cycles, how many copies are present (assuming perfect doubling)?
$2^{10} = 1\,024$, so $2^{20} = (2^{10})^2 = 1\,024^2 = 1\,048\,576$. $N = 8 \times 1\,048\,576 =$ **8 388 608** copies — from 8 molecules to over 8 million in roughly an hour of cycling, illustrating why PCR can generate ample material for analysis (e.g. gel electrophoresis) from a minute forensic or clinical sample.

Ví dụ mẫu — how many cycles are needed?

Starting with 1 target molecule, how many complete PCR cycles are needed for the copy number to first exceed 1 million (10^6)?
We need the smallest integer n such that $2^n > 1\,000\,000$. $2^{19} = 524\,288$ (not enough); $2^{20} = 1\,048\,576$ (exceeds 1 million). So **n = 20** cycles are required.

VN **GIẢI THÍCH TIẾNG VIỆT**
PCR nhân bản một đoạn DNA đích theo cấp số nhân qua 3 bước lặp lại: **biến tính** (tách 2 mạch ở $\approx 95\,^{\circ}$C), **gắn mồi** (mồi bắt cặp với vùng đích ở ≈ 50–$65\,^{\circ}$C), **kéo dài** (*Taq* polymerase chịu nhiệt tổng hợp mạch mới ở $\approx 72\,^{\circ}$C). Sau n chu kỳ, từ 1 phân tử ban đầu sẽ có khoảng 2^n bản sao — tăng theo cấp số nhân rất nhanh (chỉ sau 20 chu kỳ đã hơn 1 triệu bản sao).

14.4 Gel electrophoresis

Principle

DNA fragments (e.g. from a restriction digest, or the products of PCR) are loaded into wells cut into an **agarose gel**, submerged in a buffer, and an electric current is applied across the gel. Because DNA's sugar-phosphate backbone carries a **negative charge** (from phosphate groups), all fragments migrate toward the **positive electrode (anode)**. The agarose gel acts as a molecular sieve: **smaller fragments** move more easily through the gel's pore matrix and therefore travel **further** in a given time than **larger fragments**, which are held back more by the matrix. After running, fragments are visualised by staining with a dye that binds DNA and fluoresces under UV light. A **DNA ladder (marker)** — a mixture of fragments of known, standard sizes — is run alongside the samples in its own lane, allowing the sizes of unknown sample fragments to be estimated by comparing how far they have travelled relative to the ladder bands.

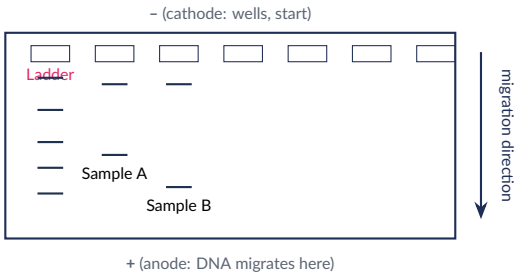

Figure 14.2 — Gel electrophoresis: DNA loaded in wells at the negative end migrates toward the positive electrode; smaller fragments (further bands) travel further than larger fragments (bands closer to the well). A DNA ladder of known fragment sizes allows unknown fragment sizes to be estimated.

Applications

DNA profiling (fingerprinting): certain non-coding regions of the genome contain short, repeated sequences (**short tandem repeats, STRs**) whose *number of repeats* varies considerably between individuals. After cutting/amplifying these regions and running gel electrophoresis, each person produces a distinctive pattern of band sizes — used in **paternity testing** (a child's bands should match one band from each parent at each STR locus), **forensic identification** (comparing a crime-scene DNA sample's band pattern against a suspect's), and comparing **restriction fragment length patterns** more generally between individuals or species.

Ví dụ mẫu — paternity-style gel interpretation

A gel shows the DNA band pattern (at one STR locus) for a mother, a child, and two candidate fathers, Man 1 and Man 2. The child has two bands: one matches a band present in the mother's lane; the other matches a band present *only* in Man 1's lane, not Man 2's. Which man is more likely to be the biological father, and why?

A child inherits one allele (one band, at this locus) from each biological parent. Since one of the child's two bands is already accounted for by the mother, the *other* band must have come from the biological father. Because that second band matches a band present in **Man 1's** lane but is absent from Man 2's lane, **Man 1** is the more likely biological father (Man 2 is excluded, since he does not carry the allele/band the child must have inherited paternally).

Ví dụ mẫu — forensic gel interpretation

DNA extracted from a crime scene sample is amplified by PCR and run on a gel alongside DNA from three suspects, using multiple STR loci. Suspect 2's band pattern matches the crime-scene sample exactly at every locus tested; Suspects 1 and 3 each differ from the crime-scene sample at several loci. What conclusion can be drawn, and what is one important limitation of this conclusion?

An exact match across multiple independent STR loci makes it **very likely** that the crime-scene DNA came from Suspect 2 (the probability of an unrelated person matching by chance at many independent loci simultaneously is extremely low). However, this is a statistical/probabilistic conclusion, not absolute proof: a full match does not, by itself, establish how or when the DNA was deposited at the scene, and (rarely) close relatives can share several STR alleles, so profiling results are normally considered alongside other evidence rather than in isolation.

VN **GIẢI THÍCH TIẾNG VIỆT**

Điện di gel tách các đoạn DNA theo kích thước: DNA tích điện âm nên di chuyển về cực dương (anode); đoạn **nhỏ hơn** di chuyển **xa hơn** qua mạng lưới gel agarose trong cùng thời gian. **Thang DNA chuẩn** (DNA ladder) có kích thước đã biết, dùng để so sánh và ước lượng kích thước băng mẫu. Ứng dụng: **giám định DNA** (xác định huyết thống, pháp y) dựa trên số lần lặp lại của các đoạn lặp ngắn (STR) — mỗi người có kiểu băng đặc trưng.

14.5 Gene cloning and recombinant vectors

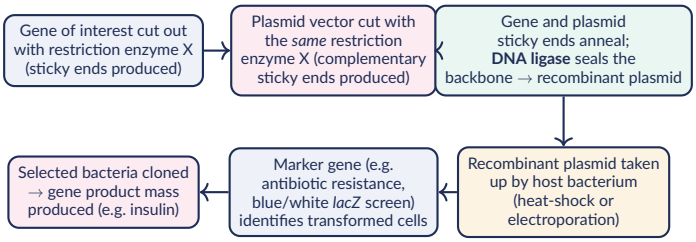

Figure 14.3 — Constructing and using a recombinant plasmid to mass-produce a gene product.

Why the same restriction enzyme must cut both DNA sources

The gene of interest and the plasmid vector are cut with the *same* restriction enzyme, so that both are left with **identical, complementary sticky ends**. These sticky ends can then base-pair (anneal) with one another regardless of their different origins, temporarily holding the gene inside the opened plasmid. **DNA ligase** then catalyses the formation of new phosphodiester bonds in the sugar-phosphate backbone, permanently sealing the gene into the plasmid to form a stable, continuous **recombinant DNA** molecule.

Transformation

Transformation is the uptake of foreign (recombinant) DNA by a host cell. Bacterial cell membranes do not normally allow plasmid DNA to cross freely, so cells must be made temporarily permeable, commonly by: **heat shock** (bacteria are first treated with calcium ions/calcium chloride to weaken and destabilise the cell membrane, then briefly heated, e.g. to $42\,^{\circ}\text{C}$, which creates temporary pores that let plasmid DNA enter before the membrane reseals), or **electroporation** (a brief high-voltage electric pulse creates temporary pores in the membrane through which plasmid DNA can enter).

Marker genes and blue/white screening

Not every host cell takes up a recombinant plasmid successfully, so a **marker gene** on the plasmid is used to identify which cells have. A simple marker is an **antibiotic resistance gene**: only bacteria that took up the plasmid (and therefore the resistance gene) survive when grown on a medium containing that antibiotic. A more precise method, **blue/white screening**, uses a plasmid carrying a functional *lacZ* gene (which encodes an enzyme that breaks down a colourless substrate, X-gal, into a blue product) with the gene of interest's insertion site located *within* the *lacZ* gene itself. If the gene of interest is *not* inserted, *lacZ* remains intact and functional, so colonies grown on X-gal-containing medium turn **blue**. If the gene of interest *is* successfully inserted, it physically disrupts (inactivates) the *lacZ* gene, so no functional enzyme is made and colonies remain **white** — white colonies are therefore the ones that have successfully taken up the plasmid *with* the gene of interest inserted, and are selected for further culture.

Colony colour on X-gal medium	*lacZ* status	Interpretation
Blue	Intact, functional (uninterrupted)	Plasmid present but *without* the gene of interest inserted
White	Disrupted (interrupted by inserted gene)	Plasmid present *with* the gene of interest successfully inserted — select these colonies
No growth (on antibiotic-containing medium)	—	Cell never took up any plasmid at all

Table 14.1 — Blue/white screening logic (combined with an antibiotic-resistance marker to first exclude non-transformed cells).

Ví dụ mẫu — blue/white screening reasoning

Bacteria are transformed with a plasmid carrying both an ampicillin-resistance gene and a *lacZ* gene interrupted by the insertion site for a gene of interest. The transformed culture is spread on agar containing both ampicillin and X-gal. Some colonies fail to grow at all; among those that grow, some are blue and some are white. Explain the significance of each outcome and which colonies should be selected for further culture.

Colonies that **fail to grow** never took up the plasmid at all (they have no ampicillin-resistance gene, so the antibiotic kills them) — these are excluded automatically by the selective medium. Among the surviving (ampicillin-resistant, therefore plasmid-containing) colonies, **blue** colonies have an intact, functional *lacZ* gene, meaning the gene of interest was *not* inserted into their plasmid (re-ligation of the vector without the insert). **White** colonies have a *disrupted lacZ* gene, meaning the gene of interest interrupted *lacZ* upon successful insertion — these **white colonies** are the ones that contain the recombinant plasmid *with* the gene of interest, and are the ones selected for further culture and use.

Ví dụ mẫu — choosing a compatible pair of restriction enzymes

A gene of interest is flanked by recognition sites for restriction enzyme *EcoRI* on one side. A researcher must choose which restriction enzyme to use to cut the plasmid vector open. Which enzyme should be chosen, and why?

The plasmid must also be cut with *EcoRI* (i.e. the *same* restriction enzyme used on the gene of interest), because *EcoRI* leaves a specific, characteristic single-stranded sticky-end sequence; only a fragment cut by the identical enzyme will have a **complementary** sticky end able to base-pair with the gene's sticky end. Using a *different* restriction enzyme on the plasmid would produce a different (non-complementary) sticky end (or a blunt end), so the gene and plasmid would not anneal correctly and DNA ligase would not be able to join them into a stable recombinant molecule.

VN **GIẢI THÍCH TIẾNG VIỆT**

Cắt gen mong muốn và plasmid vector bằng **cùng một loại** enzyme cắt giới hạn để tạo đầu dính bổ sung nhau; **DNA ligase** nối chúng lại thành plasmid tái tổ hợp. Vi khuẩn được **biến nạp** (làm màng thấm tạm thời bằng sốc nhiệt hoặc xung điện) để nhận plasmid. **Gen chỉ thị** (VD: gen kháng kháng sinh, hoặc hệ *lacZ* trong sàng lọc xanh/trắng) giúp xác định tế bào nào đã nhận thành công plasmid tái tổ hợp — khuẩn lạc **trắng** là khuẩn lạc đã chèn thành công gen mong muốn (làm hỏng gen *lacZ*), khuẩn lạc **xanh** là khuẩn lạc chỉ nhận plasmid mà không có gen chèn vào.

14.6 Genetically modified organisms

Principle and named examples

A **genetically modified (GM) organism** carries a gene, inserted using recombinant DNA technology, that did not previously exist in its genome (often from a completely different species). Named real-world examples: **herbicide-resistant crops** (e.g. soybean modified to tolerate a broad-spectrum herbicide, allowing weeds to be sprayed without harming the crop); **Bt crops** (e.g. Bt maize/cotton), carrying a gene from the soil bacterium *Bacillus thuringiensis* that encodes a protein toxic to specific insect pests but harmless to humans and most other organisms, reducing the need for chemical insecticide spraying; and **"Golden Rice"**, engineered with genes for beta-carotene synthesis (a vitamin A precursor) in the rice grain, intended to help address vitamin A deficiency in populations where rice is a staple food.

Reported benefits commonly cited for GM crops include increased yield/reduced crop loss, reduced chemical pesticide use (Bt crops), and improved nutritional content (Golden Rice). Reported concerns raised by critics and various regulatory bodies include: potential unintended ecological effects (e.g. gene flow to wild relatives via cross-pollination, effects on non-target insects), the development of herbicide- or pesticide-resistant weeds/pests over time, socioeconomic concerns about corporate control of seed supply and patenting, and consumer demand for labelling and choice. These are presented here as reported positions in an ongoing public and scientific discussion, not as settled conclusions.

VN **GIẢI THÍCH TIẾNG VIỆT**

Sinh vật biến đổi gen (GMO) mang một gen được chèn vào bằng công nghệ DNA tái tổ hợp, thường từ loài khác. Ví dụ thực tế: cây trồng **kháng thuốc diệt cỏ**, cây trồng **Bt** (mang gen độc tố diệt côn trùng gây hại từ vi khuẩn *Bacillus thuringiensis*), và **gạo vàng** (Golden Rice, mang gen tổng hợp beta-carotene — tiền chất vitamin A). Các lợi ích và lo ngại về GMO được trình bày ở đây một cách khách quan, như các quan điểm đã được ghi nhận, không đưa ra kết luận riêng.

Ví dụ mẫu — reasoning about a Bt crop

A cotton farmer switches from a conventional cotton variety to a Bt cotton variety carrying a gene from *Bacillus thuringiensis*. Explain the mechanism by which this reduces crop damage from a specific caterpillar pest, and state one reported concern regulators monitor for.

The inserted *Bt* gene is transcribed and translated within the cotton plant's own cells, producing a protein that is toxic specifically to certain insects (including the caterpillar pest) when ingested, but that has no toxic effect on humans, most beneficial insects, or other non-target organisms. Because the toxin is produced continuously inside the plant itself, less external chemical insecticide needs to be sprayed to control the pest. A reported concern regulators monitor for is the gradual evolution of **Bt-resistant pest populations** through natural selection (individuals with a chance mutation for resistance surviving and reproducing disproportionately), which is why non-Bt "refuge" areas are often planted alongside Bt crops to slow this process.

14.7 Gene therapy

	Somatic cell gene therapy	Germline gene therapy
Target cells	Body (somatic) cells of the affected individual only (e.g. lung epithelial cells in cystic fibrosis)	Gametes or very early embryos
Is the change inherited?	**No** — effects are confined to the treated individual and are *not* passed to offspring	**Yes** — the change would be passed on to all future generations
Current status	Used/trialled to treat genetic disorders in affected individuals	Banned or highly restricted for use in humans in most jurisdictions, on safety and ethical grounds
Example	Delivering a functional *CFTR* gene copy to airway cells to treat cystic fibrosis	Editing a human embryo's genome so the change is inherited by all its descendants (not an established clinical practice)

Table 14.2 — Somatic versus germline gene therapy.

Delivery methods and challenges

Corrective/functional genes are commonly delivered using **modified viral vectors** (a virus's own disease-causing genes are removed and replaced with the therapeutic gene, exploiting the virus's natural ability to insert genetic material into host cells) or **liposomes** (small spherical vesicles made of a lipid bilayer, similar to a cell membrane, which can fuse with the target cell's membrane and deliver DNA without provoking the immune response a viral vector might trigger). Key challenges include: the body's **immune response** against viral vectors (reducing effectiveness, especially on repeat treatment), the **efficiency** of delivering the gene into a high enough proportion of target cells, and the **duration of effect** (many treated cells are eventually replaced by untreated ones through normal cell turnover, so treatment may need to be repeated).

VN **GIẢI THÍCH TIẾNG VIỆT**

Liệu pháp gen soma: sửa/chèn gen vào tế bào cơ thể (không phải tế bào sinh dục) của người bệnh (VD: xơ nang) — không di truyền cho đời con. **Liệu pháp gen mầm**: sẽ làm thay đổi giao tử/phôi, do đó **di truyền được** cho các thế hệ sau — bị cấm hoặc hạn chế nghiêm ngặt ở hầu hết các quốc gia đối với con người. Phương tiện chuyển gen: vector virus (đã loại bỏ gen gây bệnh) hoặc liposome (túi lipid). Thách thức: đáp ứng miễn dịch, hiệu quả chuyển gen, và thời gian tác dụng có thể không kéo dài do tế bào được thay thế theo thời gian.

Ví dụ mẫu — classifying a gene therapy scenario

A research team corrects the faulty *CFTR* gene in the lung airway cells of a patient with cystic fibrosis, using a modified viral vector delivered by inhaler. A separate, hypothetical proposal suggests instead editing the genome of a very early human embryo so that the correction is present in every cell of the resulting individual, including their future gametes. Classify each scenario and explain the key difference in consequence between them.

The first scenario is **somatic cell gene therapy**: only the patient's own lung airway cells are targeted, so the corrected gene is confined to that individual and is *not* passed on to any offspring they may have. The second (hypothetical) scenario is **germline gene therapy**: editing a very early embryo alters the genome of essentially every cell that develops from it, including the gametes, so the correction (and any unintended, off-target changes) *would* be inherited by all of that individual's future descendants. This far-reaching, heritable consequence — affecting individuals who cannot themselves consent to the procedure — is the key reason germline gene therapy is banned or highly restricted for human use in most jurisdictions, while somatic gene therapy is used/trialled clinically.

14.8 Genetic screening and counselling

DNA probes and hybridisation

A **DNA probe (gene probe)** is a short, single-stranded DNA sequence, labelled with a fluorescent or radioactive marker, whose base sequence is **complementary** to a specific target DNA sequence (e.g. a known disease-causing allele). When mixed with a sample of (denatured, single-stranded) DNA under suitable conditions, the probe will **hybridise** (base-pair) specifically with its complementary target sequence, if present, and nowhere else — the labelled, bound probe can then be detected (visualised under UV for a fluorescent label, or by exposure to photographic film for a radioactive label), revealing whether the target sequence (e.g. a disease allele) is present in the sample. **PCR** is commonly used first, to amplify a small DNA sample (e.g. from an embryonic or prenatal cell sample) to a quantity sufficient for reliable probe-based or sequence analysis.

Types of genetic testing

Prenatal testing: testing a fetus (via cells obtained by, e.g., amniocentesis or chorionic villus sampling) for a genetic condition before birth. **Carrier testing**: testing an individual with no symptoms to determine whether they carry one copy of a recessive disease allele, relevant to family planning. **Presymptomatic testing**: testing an individual (often with a family history) for an allele associated with a late-onset condition (e.g. Huntington's disease) before any symptoms appear.

Genetic counselling provides individuals and families with clear, factual, non-judgemental information about the genetic risks revealed by testing (e.g. the probability of an offspring inheriting a condition, using pedigree analysis and/or Hardy–Weinberg-style probability calculations), and the range of options available (e.g. further testing, family planning choices, or preparing for the practical/medical implications of a result), leaving decisions to the individuals concerned. Associated ethical/social issues, raised and discussed factually rather than resolved here, include: the **privacy** of genetic information, the potential for **insurance or employment discrimination** based on genetic test results, and ensuring genuinely **informed consent** before any test is carried out (including the right not to be tested, e.g. for an untreatable late-onset condition).

VN GIẢI THÍCH TIẾNG VIỆT

Đầu dò DNA (gene probe): một đoạn DNA mạch đơn, có gắn chất đánh dấu (huỳnh quang/phóng xạ), có trình tự **bổ sung** với trình tự đích cần tìm — nó sẽ **lai** (hybridise) đặc hiệu với trình tự đích nếu có trong mẫu, giúp phát hiện alen gây bệnh. Các loại sàng lọc: **sàng lọc trước sinh**, **sàng lọc người mang gen** (không có triệu chứng), **sàng lọc tiền triệu chứng** (bệnh khởi phát muộn). **Tư vấn di truyền** cung cấp thông tin khách quan về nguy cơ di truyền và các lựa chọn, không áp đặt quyết định. Các vấn đề đạo đức liên quan: bảo mật thông tin di truyền, nguy cơ phân biệt đối xử (bảo hiểm/việc làm), và sự đồng thuận có hiểu biết đầy đủ.

14.9 CRISPR--Cas9 gene editing

Basic mechanism

CRISPR–Cas9 is a more precise, efficient and low-cost alternative to earlier recombinant DNA methods for editing a genome directly. A short synthetic **guide RNA (gRNA)**, designed to be complementary to a specific target DNA sequence, binds the **Cas9** enzyme and directs it to that exact site in the genome (by the guide RNA base-pairing with the complementary target DNA sequence). Cas9 then acts as "molecular scissors", making a precise double-strand cut in the DNA at that site. The cell's own DNA repair machinery then either (a) repairs the cut imprecisely, disrupting (**knocking out**) the gene, or (b) if a repair template (a designed DNA sequence) is supplied alongside, incorporates it during repair, allowing a **precise, targeted edit** (correcting a faulty sequence, or inserting a new one) at that exact location.

Compared with older recombinant DNA approaches (which typically insert a gene at a semi-random genomic location using a vector), CRISPR–Cas9 can target an **exact, chosen site** in the genome, is faster and considerably cheaper to design and use (only a new short guide RNA sequence needs to be synthesised to retarget it to a different gene), and has made precise gene editing far more accessible for research laboratories worldwide, with growing exploration of potential therapeutic applications.

VN GIẢI THÍCH TIẾNG VIỆT

CRISPR–Cas9: một RNA dẫn đường (guide RNA) đưa enzyme Cas9 đến đúng vị trí trình tự DNA bổ sung với nó; Cas9 cắt DNA tại vị trí chính xác đó, cho phép làm hỏng gen (knockout) hoặc, nếu có mẫu sửa chữa đi kèm, chỉnh sửa gen chính xác. So với công nghệ DNA tái tổ hợp cũ, CRISPR–Cas9 nhanh hơn, rẻ hơn, và chính xác hơn nhiều, giúp việc chỉnh sửa gen trở nên phổ biến hơn trong nghiên cứu và có tiềm năng ứng dụng điều trị.

Practice

Bài tập luyện tập

State, in the correct order, the four general steps of recombinant DNA technology, from isolating a gene of interest to obtaining the desired gene product.

Lời giải chi tiết

(1) Isolate or synthesise the gene of interest; (2) insert it into a vector (e.g. a plasmid) to form recombinant DNA; (3) introduce the recombinant vector into a host cell (transformation); (4) select successfully transformed host cells and allow them to express/clone the gene (e.g. to mass-produce a protein).

Bài tập luyện tập

Why are "sticky ends" produced by restriction enzymes especially useful in recombinant DNA technology, compared with blunt ends?

(A) Sticky ends make the DNA fragment permanently double the length

(B) Sticky ends provide single-stranded overhangs that can base-pair specifically with any other fragment cut by the same enzyme, allowing reliable, specific joining

(C) Sticky ends prevent DNA ligase from working

(D) Sticky ends only occur in eukaryotic DNA

Lời giải chi tiết

Sticky ends are short single-stranded overhangs that will specifically base-pair (anneal) with the complementary overhang produced by the *same* restriction enzyme cutting a different DNA molecule, allowing a gene and a vector from different sources to be joined together reliably before DNA ligase seals the backbone. **(B)**.

Bài tập luyện tập

Explain why reverse transcriptase, rather than cutting a gene directly out of genomic DNA with a restriction enzyme, is normally used to obtain a copy of a human gene for insertion into a bacterium.

Lời giải chi tiết

Human (eukaryotic) genes typically contain **introns**, non-coding sequences that must be removed by splicing after transcription to produce mature mRNA. Bacteria lack the splicing machinery needed to remove introns, so a gene cut directly from human genomic DNA (which still contains introns) would not be expressed correctly in a bacterium. Reverse transcriptase synthesises **cDNA** from mature (already-spliced, intron-free) mRNA, giving an intron-free copy of the gene that a bacterial host can express correctly.

Bài tập luyện tập

Starting with a single target DNA molecule, calculate the number of copies present after 8 PCR cycles (assuming perfect doubling each cycle).

(A) 8
(B) 64
(C) 256
(D) 512

Lời giải chi tiết

$N = 1 \times 2^8 =$ **256**. **(C)**.

Bài tập luyện tập

A PCR reaction starts with 3 target DNA molecules and is run for 12 cycles. Calculate the number of DNA copies present at the end, showing your working.

Lời giải chi tiết

$2^{12} = 4\,096$. $N = 3 \times 4\,096 =$ **12 288** molecules.

Bài tập luyện tập

A forensic lab needs at least $500\,000$ copies of a target sequence to run a reliable analysis, starting from a single template molecule. What is the minimum number of complete PCR cycles required?

(A) 16
(B) 18
(C) 19
(D) 20

Lời giải chi tiết

$2^{18} = 262\,144$ (not enough). $2^{19} = 524\,288$ (exceeds $500\,000$). Minimum **19** cycles. **(C)**.

Bài tập luyện tập

Explain why *Taq* polymerase, rather than a standard (non-heat-tolerant) DNA polymerase, is essential for PCR.

Lời giải chi tiết

Every PCR cycle includes a denaturation step at $\approx 95\,^{\circ}$C to separate the DNA strands. A standard DNA polymerase would be permanently denatured (its tertiary structure destroyed) at this temperature and would have to be replaced every single cycle. *Taq* polymerase, isolated from the heat-tolerant bacterium *Thermus aquaticus*, remains structurally stable and enzymatically active even after repeated heating to $95\,^{\circ}$C, so a single addition works for the entire multi-cycle reaction, making PCR practical and automatable.

Bài tập luyện tập

During PCR, what is the specific role of the primers, and why must there be two different primers (rather than one) for each target region?

Lời giải chi tiết

Primers are short, single-stranded DNA sequences complementary to the sequences immediately flanking the target region; they anneal to the single-stranded template during the annealing step and provide the free 3′ end that *Taq* polymerase requires to begin synthesising a new strand. Because the two original strands of the double helix run in opposite (antiparallel) directions, **two different primers** are needed — one complementary to each strand — so that new synthesis proceeds inward from both flanking ends, amplifying exactly the target region between them.

Bài tập luyện tập

On a gel, fragment P has travelled 4.2 cm from the well and fragment Q has travelled 1.5 cm from the well, after the same running time. What can be concluded about their relative sizes?

(A) Fragment P is larger than fragment Q

(B) Fragment P is smaller than fragment Q, since smaller fragments migrate faster/-further

(C) No conclusion can be drawn without knowing the DNA sequence

(D) Fragment P must be positively charged

Lời giải chi tiết

Smaller DNA fragments move more easily through the agarose gel's pore matrix and so travel further from the well in a given time. Fragment P, having travelled further, must be **smaller** than fragment Q. **(B)**.

Bài tập luyện tập

Explain the purpose of running a DNA ladder (marker) in its own lane alongside experimental samples during gel electrophoresis.

Lời giải chi tiết

A DNA ladder is a mixture of DNA fragments of known, standard sizes. By comparing how far each experimental sample band has travelled relative to the ladder bands (which have known sizes), the approximate size of each unknown sample fragment can be estimated — the ladder acts as a size reference/calibration scale for the gel.

Bài tập luyện tập

A paternity gel test shows a child has two bands at a given STR locus: one matching a band in the mother's lane, and the other matching a band present in the alleged father's lane but absent from an unrelated control male's lane. What can be concluded?

(A) The alleged father is excluded as the biological father

(B) The alleged father is consistent with being the biological father, since the child's non-maternal band matches his

(C) No conclusion is possible from a single locus

(D) The mother's DNA is irrelevant to this analysis

Lời giải chi tiết

The child must inherit one band at this locus from each biological parent. The maternal band is accounted for; the remaining (paternal) band matches the alleged father specifically, which is consistent with (though, at a single locus alone, not absolute proof of) his being the biological father. **(B)**.

Bài tập luyện tập

Crime-scene DNA is compared against three suspects at five independent STR loci. Suspect C matches the crime-scene sample exactly at all five loci; Suspects A and B each mismatch at two or more loci. Explain why matching at *multiple independent* loci gives much stronger evidence than matching at just one locus.

Lời giải chi tiết

Any single STR locus has a reasonably common range of alleles shared across the population, so a chance match at one locus alone is not especially rare. However, because different STR loci vary largely independently of one another, the probability of an unrelated person matching by chance at *every one* of several independent loci simultaneously is the product of each individual (small) probability — an extremely small combined probability. A full match across multiple loci therefore gives much stronger statistical evidence of a true match than a single-locus match would.

Bài tập luyện tập

Why must the plasmid vector and the gene of interest be cut with the same restriction enzyme before they can be joined by DNA ligase?

(A) It is not actually necessary; any enzyme combination works equally well

(B) The same enzyme produces complementary sticky ends on both DNA molecules, allowing them to base-pair before ligase seals the backbone

(C) Different enzymes always destroy plasmid DNA

(D) It is purely a historical convention with no functional reason

Lời giải chi tiết

Using the same restriction enzyme ensures both the gene of interest and the opened plasmid have the identical, complementary sticky-end sequence, allowing them to anneal correctly by base-pairing before DNA ligase forms new phosphodiester bonds to seal them into one continuous recombinant molecule. **(B)**.

Bài tập luyện tập

Describe two methods by which bacterial cells can be made to take up recombinant plasmid DNA (transformation), and explain briefly how each works.

Lời giải chi tiết

Heat shock: bacteria are first treated with calcium ions (e.g. calcium chloride solution), which help destabilise/neutralise charge on the cell membrane and plasmid DNA, then briefly heated (e.g. to $42\,^{\circ}$C) before rapid cooling; this creates temporary pores in the membrane through

which plasmid DNA can enter before the membrane reseals. **Electroporation**: a brief pulse of high-voltage electric current is applied to the cells, creating temporary pores in the membrane through which DNA can pass directly into the cell.

Bài tập luyện tập

In blue/white screening, a bacterial colony grown on ampicillin/X-gal medium appears blue. What does this indicate about that colony?

(A) The colony never took up any plasmid

(B) The colony took up a plasmid, but the gene of interest was not successfully inserted (the lacZ gene remains functional)

(C) The colony took up a plasmid with the gene of interest successfully inserted

(D) The colony is resistant to X-gal

Lời giải chi tiết

Growth on ampicillin confirms the colony took up *some* plasmid (it carries the ampicillin-resistance marker); a **blue** colour means the *lacZ* gene is still intact and functional (producing the enzyme that turns X-gal blue), which only happens if the gene of interest was *not* inserted into (and therefore did not disrupt) *lacZ*. **(B)**.

Bài tập luyện tập

Following on from the previous question, which colour colony should be selected for further culture if the aim is to obtain bacteria carrying the gene of interest, and why?

Lời giải chi tiết

White colonies should be selected: a white colony indicates the *lacZ* gene has been disrupted, which only happens when the gene of interest has been successfully inserted at that site within the plasmid — so white (not blue) colonies are the ones carrying the recombinant plasmid with the gene of interest.

Bài tập luyện tập

A student wants to insert a human gene into a bacterial plasmid so that the bacterium can express a fully functional human protein. Explain why simply cutting the gene directly out of a sample of human genomic DNA with a restriction enzyme, and inserting it directly, would likely fail to produce the functional protein, and what should be done instead.

Lời giải chi tiết

Human genomic DNA for this gene contains **introns** (non-coding sequences) interspersed with the coding exons. Bacteria lack the spliceosome machinery required to remove introns from a transcript, so if the intron-containing gene were inserted directly, the bacterium would produce a faulty, non-functional (or prematurely truncated) protein. Instead, **reverse transcriptase** should be used to make an intron-free **cDNA** copy of the gene from mature (already spliced) human mRNA, which can then be inserted into the plasmid and correctly expressed by the bacterium.

Bài tập luyện tập

Bt maize contains a gene, originally from the soil bacterium *Bacillus thuringiensis*, encoding a protein toxic to certain insect pests. Explain the intended benefit of this modification and state one concern that has been raised about Bt crops.

Lời giải chi tiết

The inserted *Bt* gene allows the maize plant to produce its own insect-specific toxin, killing or deterring pests that feed on it (e.g. the European corn borer) without harming humans or most non-target organisms, and can reduce the need for external chemical pesticide spraying. A concern that has been raised is the possible development of **Bt-resistant insect populations** over time (through natural selection favouring resistant pest individuals), which is why refuge strategies (planting some non-Bt crop nearby) are recommended by regulators in some regions.

Bài tập luyện tập

"Golden Rice" has been engineered to synthesise beta-carotene in its grain. State the nutritional rationale for this modification.

(A) Beta-carotene increases the rice's resistance to a fungal pathogen

(B) Beta-carotene is a precursor of vitamin A, addressing vitamin A deficiency in populations where rice is a dietary staple

(C) Beta-carotene makes the rice grow faster

(D) Beta-carotene is an antibiotic-resistance marker gene

Lời giải chi tiết

Beta-carotene is a metabolic precursor the body converts into **vitamin A**; engineering rice grain to synthesise it is intended to help address vitamin A deficiency (a significant public health problem in some regions) where rice forms a large part of the diet. **(B)**.

Bài tập luyện tập

Distinguish clearly between somatic cell gene therapy and germline gene therapy, in terms of which cells are targeted and whether the change is inherited by offspring.

Lời giải chi tiết

Somatic cell gene therapy targets body (somatic) cells of the affected individual only (e.g. airway epithelial cells in cystic fibrosis); the genetic change is confined to that individual and is **not** passed on to their offspring. **Germline gene therapy** would alter gametes or very early embryos, so the genetic change **would be inherited** by all subsequent generations descended from that individual; because of the far-reaching and currently unpredictable long-term consequences of heritable changes, germline gene therapy is banned or highly restricted for human use in most jurisdictions.

Bài tập luyện tập

State two named challenges affecting the long-term success of somatic cell gene therapy using a viral vector.

(A) Cost of the vector alone, and nothing else

(B) The patient's immune response against the viral vector, and treated cells eventually being replaced by untreated cells over time (limiting duration of effect)

(C) Viral vectors always cause the target gene to mutate further

(D) There are no significant challenges once a viral vector is used

Lời giải chi tiết

Two well-documented challenges are: the body's **immune response**, which can attack the viral vector (reducing effectiveness, particularly on repeated treatment), and the **limited duration of effect**, since many treated cells are naturally replaced over time by new, untreated cells arising from cell division, meaning the therapeutic effect may fade and require repeat treatment. **(B)**.

Bài tập luyện tập

Explain what a DNA probe (gene probe) is, and describe how hybridisation allows it to detect a specific disease-causing allele in a patient's DNA sample.

Lời giải chi tiết

A DNA probe is a short, single-stranded DNA sequence, labelled with a fluorescent or radioactive marker, whose base sequence is complementary to a specific target sequence (e.g. a known disease-causing allele). When added to a sample of denatured (single-stranded) patient DNA, the probe will **hybridise** — base-pair specifically — with the target sequence if, and only if, that sequence is present in the sample. Detecting the label (e.g. fluorescence under UV, or exposure of photographic film for a radioactive label) attached to bound probe reveals whether the target disease allele is present.

Bài tập luyện tập

A woman with no family history of a genetic condition requests carrier testing before starting a family, and a genetic counsellor explains the test's meaning and limitations without recommending any particular decision. Which principle of genetic counselling does this best illustrate?

(A) Genetic counselling should always recommend against having children if any risk is found

(B) Genetic counselling should provide factual, non-judgemental information, leaving decisions to the individual/family

(C) Genetic counselling is only relevant for prenatal testing

(D) Genetic counselling replaces the need for the actual genetic test

Lời giải chi tiết

Genetic counselling is intended to communicate risks, test meanings, and available options **factually and without judgement**, respecting the individual's or family's right to make their own informed decision. **(B)**.

Bài tập luyện tập

State one social/ethical concern associated with widespread genetic screening, other than the accuracy of the test itself.

Lời giải chi tiết

Any of, e.g.: the **privacy** of an individual's genetic information (who can access test results, and how they might be stored/shared); the potential for **discrimination** by insurers or employers on the basis of genetic test results (e.g. presymptomatic risk of a late-onset disease); or ensuring genuinely **informed consent**, including an individual's right to decline testing, particularly for currently untreatable late-onset conditions.

Bài tập luyện tập

Explain, in outline, how CRISPR–Cas9 directs a precise cut to one specific site in a genome.

Lời giải chi tiết

A short synthetic **guide RNA (gRNA)** is designed to be complementary to the target DNA sequence; it binds the **Cas9** enzyme and base-pairs with the complementary sequence at the target site in the genome, directing Cas9 there specifically. Cas9 then makes a precise double-strand cut in the DNA at that exact site.

Bài tập luyện tập

After CRISPR–Cas9 cuts a target gene, no repair template is supplied. What is the likely outcome for that gene, and how does this differ from the outcome if a repair template had been supplied?

(A) The cell dies immediately in every case

(B) The cell's own repair machinery repairs the cut imprecisely, typically disrupting/-knocking out the gene; with a repair template supplied, the cell can instead incorporate the template for a precise, targeted edit

(C) Nothing happens to the DNA at all without a repair template

(D) The guide RNA itself becomes part of the genome

Lời giải chi tiết

Without a repair template, the cell's natural DNA repair pathways typically rejoin the cut ends imprecisely, introducing small insertions/deletions that disrupt (knock out) the gene's function. If a designed repair template is supplied alongside Cas9 and the guide RNA, the cell's repair machinery can instead use that template during repair, allowing a precise, chosen edit (correcting or replacing the sequence) rather than a random disruption. **(B)**.

Bài tập luyện tập

Give two reasons why CRISPR–Cas9 is considered a significant improvement over earlier recombinant DNA/gene-insertion methods for editing genomes.

Lời giải chi tiết

Any two of: (1) it can target an **exact, chosen site** in the genome (rather than inserting a gene at a semi-random location via a vector); (2) it is considerably **faster and cheaper** to redesign for a new target gene (only a new short guide RNA sequence needs to be synthesised); (3) this has made precise gene editing far more **accessible** to research laboratories, broadening the range of organisms/genes that can practically be studied or (potentially) treated.

Bài tập luyện tập

A biotechnology company wants to mass-produce human insulin using genetically modified bacteria. Outline, in the correct sequence, all the major steps required, from obtaining the human insulin gene to harvesting the insulin protein.

Lời giải chi tiết

(1) Obtain an intron-free copy of the human insulin gene, most reliably using **reverse transcriptase** to make cDNA from mature insulin mRNA (extracted from pancreatic beta cells). (2) Cut a bacterial plasmid vector open using a restriction enzyme, and if needed, add complementary sticky ends to the cDNA (or use appropriate ligation chemistry) so the two can anneal. (3) Use **DNA ligase** to seal the insulin gene into the plasmid, forming recombinant DNA. (4) **Transform** host bacteria with the recombinant plasmid (e.g. by heat shock). (5) Use a marker gene (e.g. antibiotic resistance, or blue/white screening) to **select** only bacteria that have taken up the recombinant plasmid. (6) **Culture (clone)** the selected bacteria in large fermenters, allowing them to express the human insulin gene and secrete/accumulate the insulin protein, which is then extracted and purified.

Bài tập luyện tập

A DNA sample is analysed by both PCR and gel electrophoresis in the same forensic workflow. Explain the distinct purpose each technique serves in this workflow.

Lời giải chi tiết

PCR amplifies the (often extremely small) amount of DNA obtained from a forensic sample into a much larger quantity of copies of the target sequence(s), sufficient for reliable further analysis. **Gel electrophoresis** then separates the amplified DNA fragments (e.g. at several STR loci) by size, producing a band pattern that can be compared between individuals (e.g. suspect vs. crime-scene sample) to assess whether they match.

Bài tập luyện tập

A patient with cystic fibrosis receives a functional copy of the *CFTR* gene delivered to their airway epithelial cells via a viral vector, with clinical improvement lasting several months before gradually declining. Explain, in terms of gene therapy challenges, why the benefit is not permanent.

Lời giải chi tiết

Airway epithelial cells are continually replaced through normal tissue turnover; as the originally-treated (corrected) cells are gradually replaced by new cells that never received the functional gene copy, the proportion of cells expressing functional CFTR protein declines over

time, and clinical benefit fades — illustrating the **limited duration of effect** typical of current somatic gene therapy, usually requiring repeat treatment.

Ôn tập nhanh

- Độ phóng đại = kích thước ảnh ÷ kích thước thật; luôn đưa về cùng đơn vị trước khi tính.
- Thế nước = thế áp suất + thế thẩm thấu; nước luôn di chuyển từ thế nước cao đến thế nước thấp.
- Chu kỳ tế bào gồm 4 pha: $G_1 \to S$ (nhân đôi DNA) $\to G_2 \to M$ (phân bào).
- DNA nhân đôi theo cơ chế **bán bảo toàn**; mạch dẫn đầu tổng hợp liên tục, mạch ra chậm tổng hợp gián đoạn thành các đoạn Okazaki.
- Nguyên tắc bổ sung base: A–T (2 liên kết hydro), G–X (3 liên kết hydro).
- Kiểm định χ^2: giá trị tính được nhỏ hơn giá trị tới hạn → chấp nhận H_0 (số liệu phù hợp tỉ lệ kỳ vọng).
- Hardy–Weinberg: $q = \sqrt{q^2}$ trước, rồi $p = 1 - q$, rồi $2pq$ là tỉ lệ dị hợp tử.
- Chỉ số đa dạng Simpson: $D = 1 - \sum(n/N)^2$; D càng gần 1, quần xã càng đa dạng.
- PCR: số bản sao tăng theo cấp số nhân, sau n chu kỳ $\approx 2^n$ lần ban đầu.
- Điện di gel: DNA tích điện âm, di chuyển về cực dương; đoạn nhỏ di chuyển xa hơn đoạn lớn.
- Hô hấp hiếu khí cần O_2 làm chất nhận electron cuối cùng trong chuỗi truyền electron.
- Chọn lọc tự nhiên tác động lên quần thể qua nhiều thế hệ, làm thay đổi tần số alen theo thời gian.

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SAT 1590 / 1570 / 1550	**IELTS** 8.0–9.0	**Duolingo** 110 · **PTE** 90

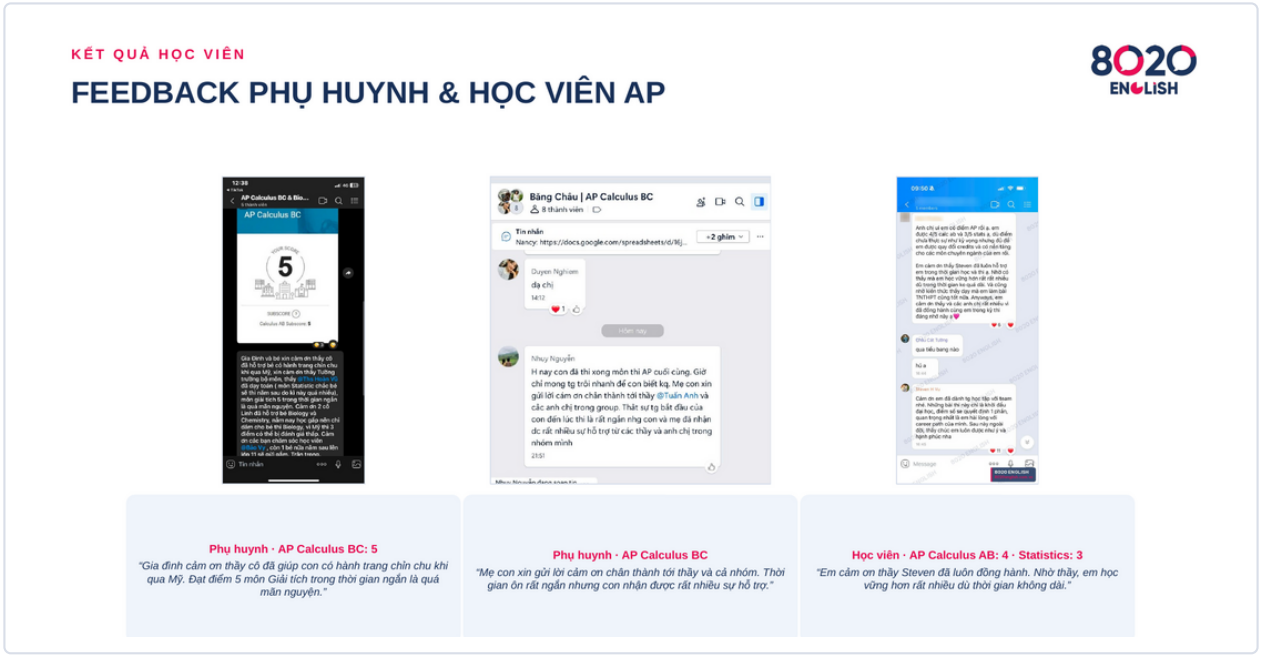
Cảm nhận học viên & phụ huynh

> *"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)

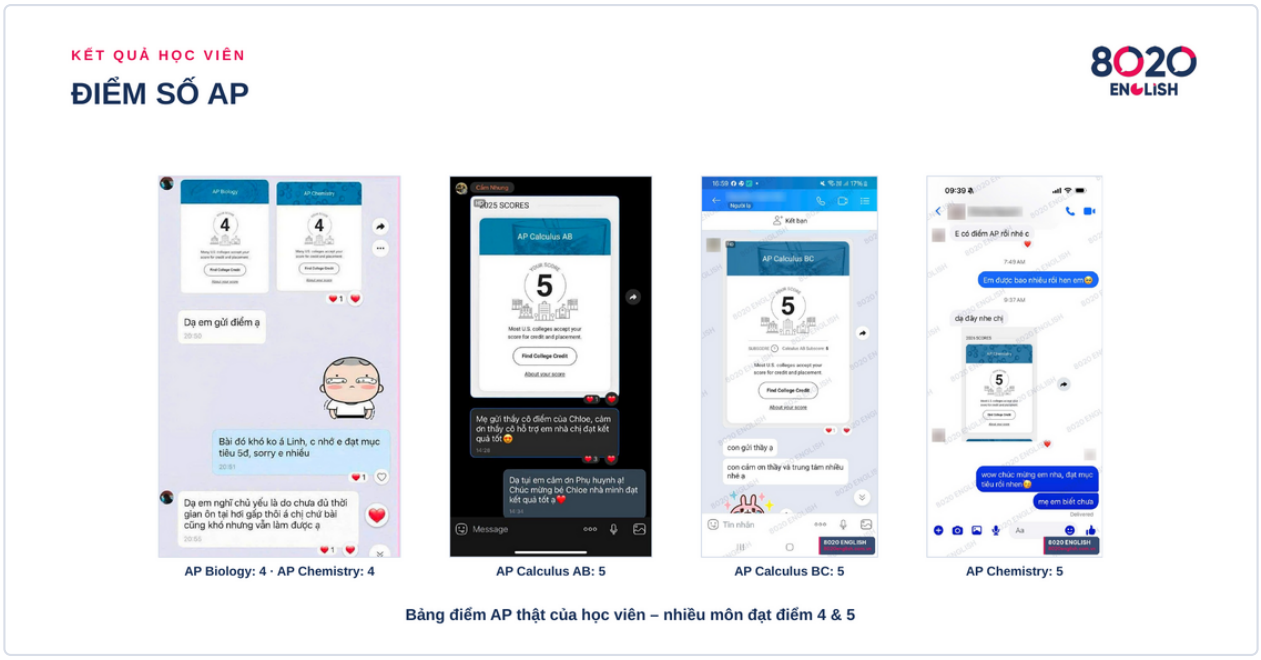
> *"Gia đình và bé xin cảm ơn thầy cô đã giúp con có hành trang chỉn chu khi qua Mỹ. Đạt điểm 5 môn Giải tích trong thời gian ngắn là quá mãn nguyện."*
>
> — Phụ huynh · AP Calculus BC 5/5

> *"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

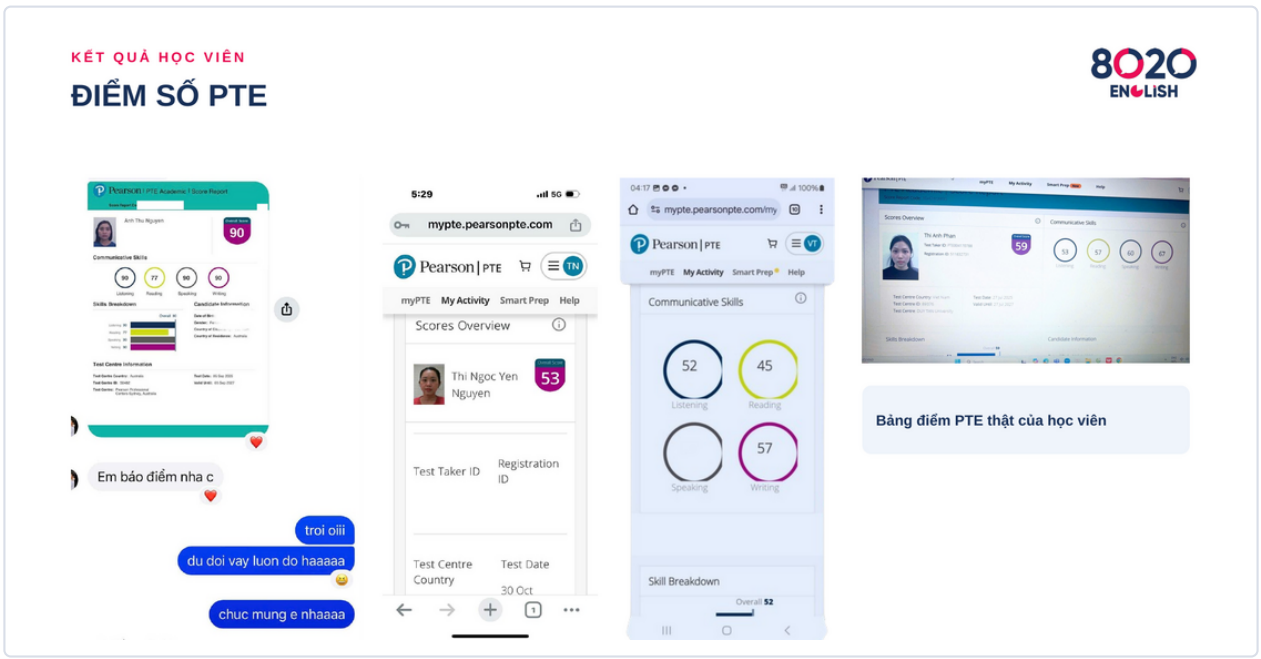


Feedback phụ huynh & học viên AP — nhiều môn đạt điểm 4 & 5

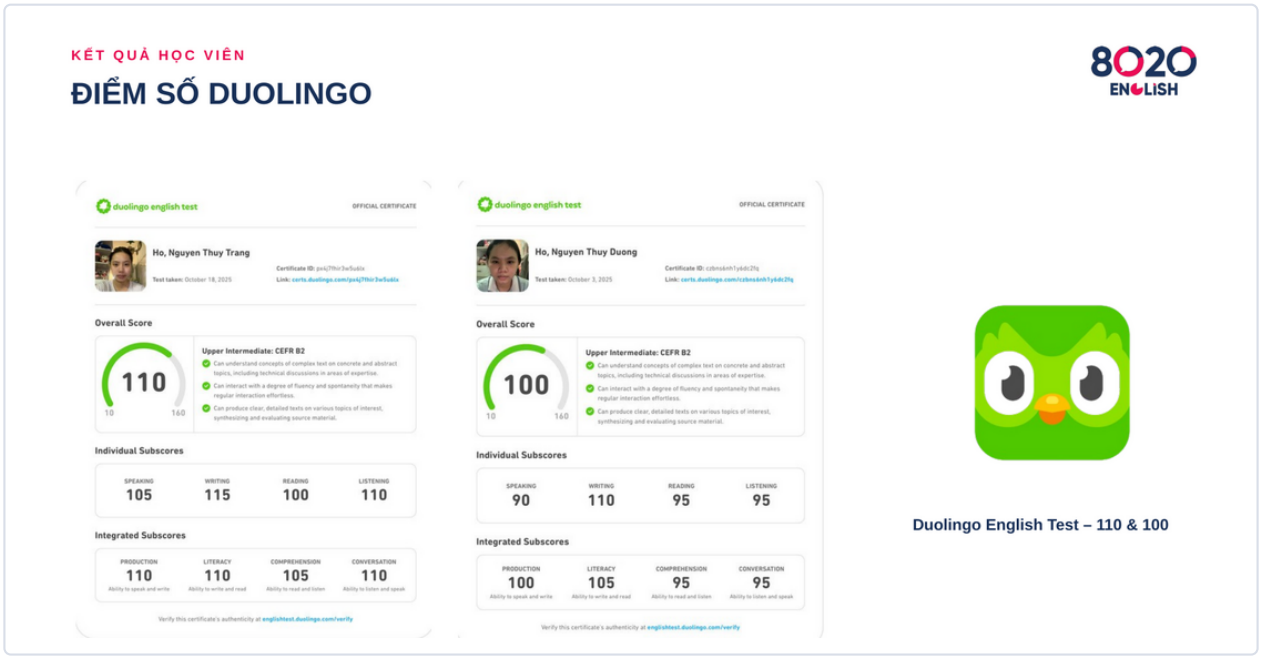
Điểm thi thật của học viên



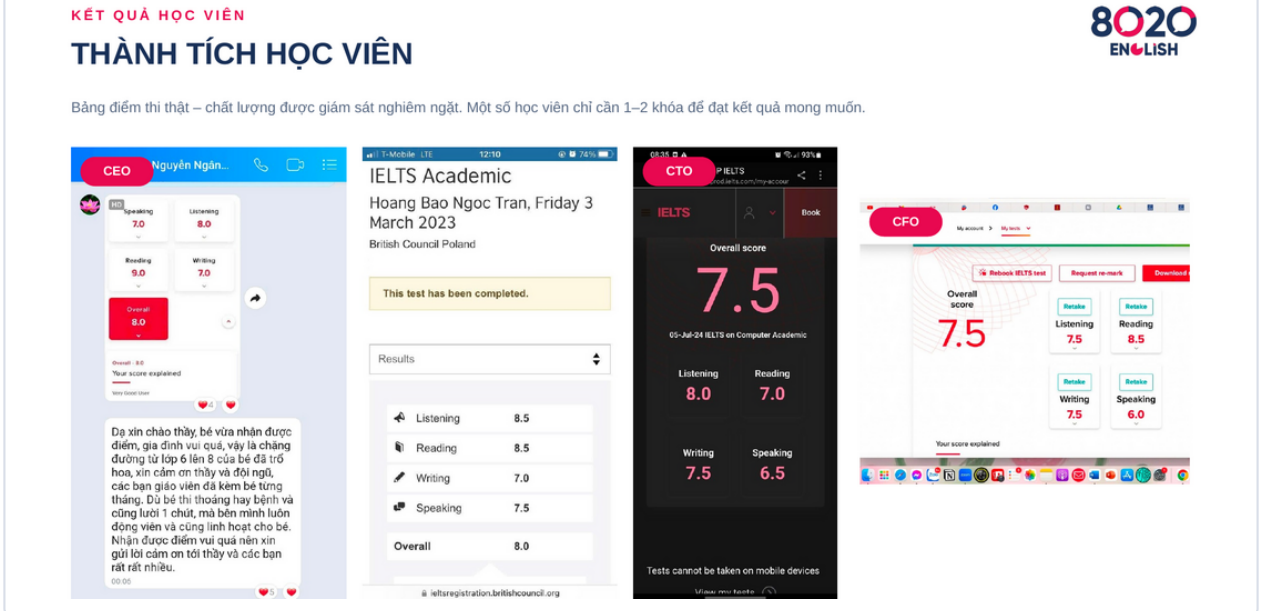
Bảng điểm AP thật — Calculus AB/BC 5/5 · Biology & Chemistry 4–5 (College Board)



Học viên 8020 — PTE Academic 90



Học viên 8020 — Duolingo English Test 110 & 100



Học viên 8020 — IELTS 8.0 / 7.5 / 8.5 (báo điểm thật)