IB Biology HL Enzymes & Cell Biology — C1.1, A1.1, D1.1

IB HL Study Guide

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Complete Study Guide

Topics Covered

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Aligned to IB Biology HL 2025 syllabus — C1.1, A1.1, A1.2, D1.1

> **IB BIOLOGY HL:** All Guides Photosynthesis & Respiration Cell Biology & Ultrastructure DNA & Gene Expression

Section 1: Enzymes — Structure & Function (C1.1)

Enzymes are **biological catalysts** — globular proteins that speed up metabolic reactions by lowering the **activation energy** (E_a). Without enzymes, essentially no metabolic reaction would proceed fast enough to sustain life at body temperature. Every enzyme is specific to one reaction or a small family of related reactions.

MEMORISE THIS

Core definitions to memorise:

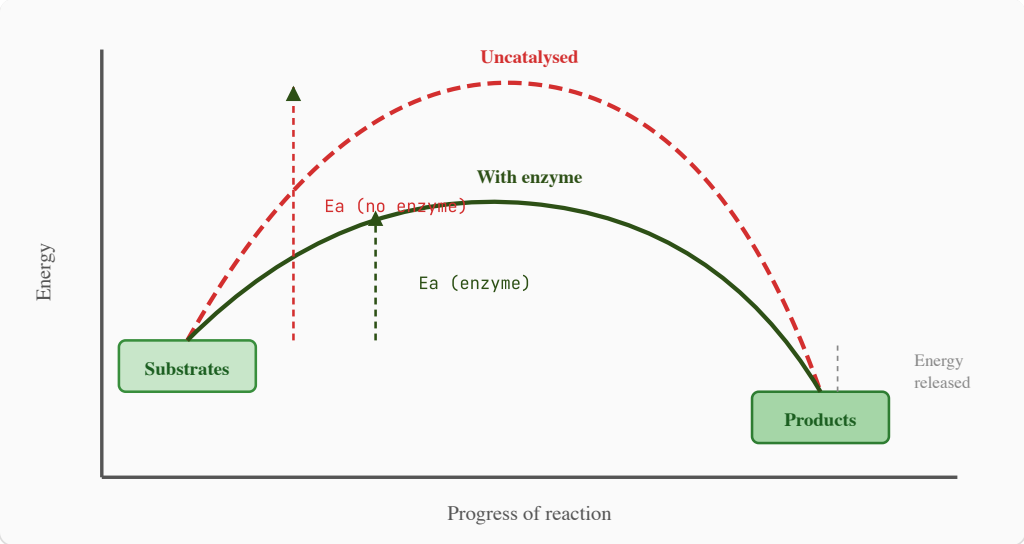
Term	Definition
Enzyme	Biological catalyst; globular protein that lowers E_a
Active site	Region of the enzyme complementary to the substrate in shape and chemistry
Substrate	The molecule on which an enzyme acts
Product	The molecule(s) formed after the reaction
Activation energy (E_a)	Minimum energy required to start a reaction
Denaturation	Permanent loss of tertiary structure (and thus function)
Metabolism	All enzyme-catalysed reactions in a cell
Anabolism	Building up complex molecules from simpler ones (e.g. protein synthesis)
Catabolism	Breaking down complex molecules into simpler ones (e.g. digestion)

1.1 How Enzymes Work

Enzymes work by binding their **substrate** at the **active site**, forming a temporary **enzyme-substrate complex** (ES complex). The active site provides an environment that lowers E_a — by straining bonds, providing an optimal microenvironment, or positioning substrates correctly for the reaction.

$$E + S \rightleftharpoons ES \rightarrow E + P$$

The enzyme is **unchanged** after the reaction and can be reused.



Energy profile: enzymes lower the activation energy without changing the overall energy change of the reaction

⚠ EXAM ALERT

Exam Alert: Enzymes **lower** E_a — they do NOT provide energy. They do NOT change the equilibrium position or the ΔG of the reaction. They only make the reaction reach equilibrium faster. This is a very common MCQ distractor.

1.2 Lock-and-Key vs Induced Fit

Two models explain enzyme-substrate interaction:

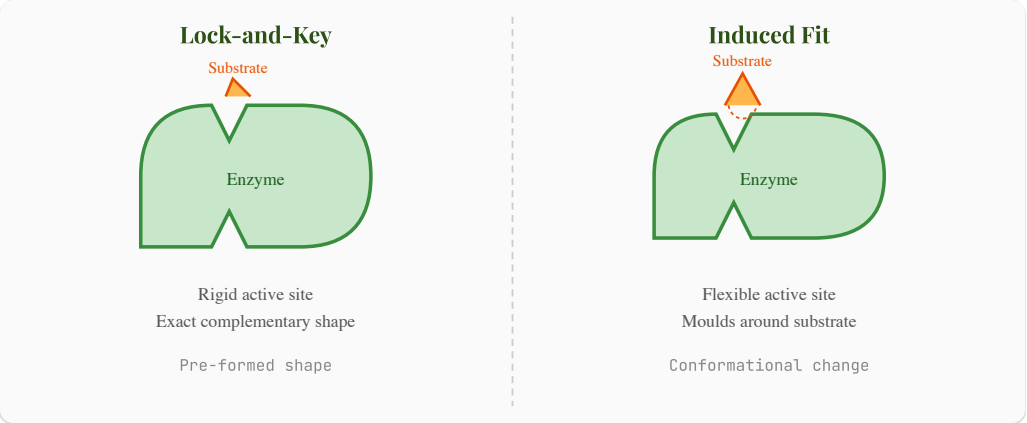
Lock-and-Key Model (Fischer, 1894):

- The active site is a rigid, pre-formed shape exactly complementary to the substrate
- Like a key fitting into a lock
- Explains specificity but is oversimplified

Induced-Fit Model (Koshland, 1958):

- The active site is flexible and moulds around the substrate upon binding
- Both enzyme AND substrate change conformation slightly

- More accurate — explains how some enzymes act on a range of similar substrates



Lock-and-key vs induced-fit models of enzyme-substrate binding

IB TIP

IB Tip: The IB syllabus expects you to describe the **induced-fit model** as the more accepted explanation. However, you must ALSO know the lock-and-key model to compare them. The key difference: induced fit explains why the enzyme slightly changes shape on binding.

1.3 Factors Affecting Enzyme Activity

Four factors control the rate of enzyme-catalysed reactions: **temperature**, **pH**, **substrate concentration**, and **enzyme concentration**.

Temperature

- As temperature increases, kinetic energy of molecules increases
- More frequent enzyme-substrate collisions → higher rate
- **Optimum temperature**: the temperature at which rate is maximum (typically ~37 C for human enzymes)
- Beyond the optimum: hydrogen bonds and weak interactions break → **denaturation**
- Active site loses its specific shape → substrate can no longer bind → rate drops to zero

EXAM ALERT

Exam Alert: Denaturation is **permanent** — the enzyme does NOT refold when cooled. At LOW temperatures, the enzyme is NOT denatured; it is simply inactive because molecules have too little kinetic energy. Students frequently confuse "inactive" with "denatured" in MCQs.

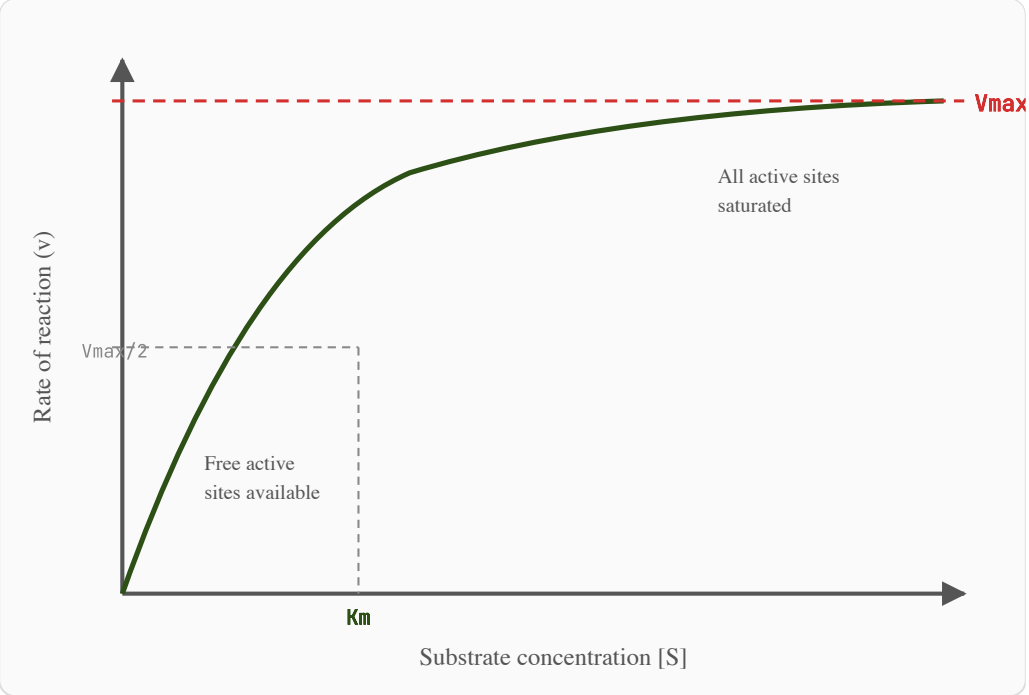
pH

- Each enzyme has an **optimum pH** (e.g. pepsin: pH 2, trypsin: pH 8)

- Extreme pH values change the ionisation of R-groups in the active site
- Disrupts ionic bonds and hydrogen bonds → changes active site shape → denaturation
- pH changes can be reversible if small, or irreversible (denaturation) if extreme

Substrate Concentration

- At low [S]: rate increases proportionally — plenty of free active sites
- At high [S]: rate plateaus — all active sites are occupied (**saturation**)
- Maximum rate at saturation is called V_{max}
- The substrate concentration at which rate = $\frac{1}{2}V_{max}$ is the **Michaelis constant** (K_m)



Michaelis-Menten curve: rate vs substrate concentration showing V_{max} and K_m

MEMORISE THIS

Memorise K_m:

K_m value	Meaning
Low K_m	Enzyme reaches $\frac{1}{2}V_{max}$ at low [S] → **high affinity** for substrate
High K_m	Enzyme needs high [S] to reach $\frac{1}{2}V_{max}$ → **low affinity** for substrate

1.4 Enzyme Inhibition HL

AHL — C1.1

Cells need ways to slow down or stop enzyme activity — otherwise reactions would run unchecked. Inhibitors are molecules that do this by interfering with the enzyme's ability to bind its substrate. The critical distinction is whether the inhibitor blocks the active site directly (competitive) or attacks from a different location and changes the

enzyme's shape (non-competitive), because this determines whether you can overcome the inhibition by adding more substrate.

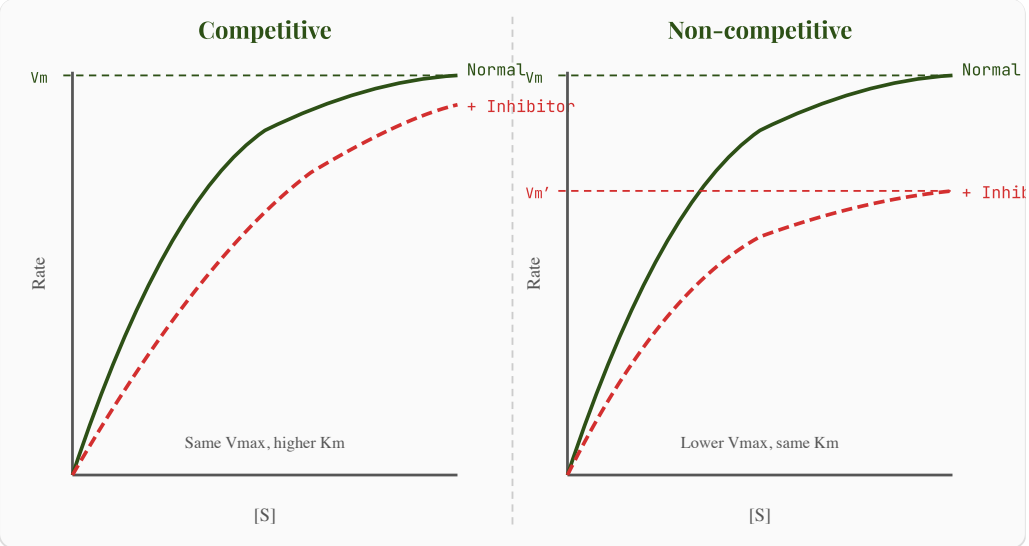
Inhibitors are molecules that reduce the rate of enzyme-catalysed reactions. Two main types:

Competitive Inhibition:

- Inhibitor has a shape **similar** to the substrate
- Binds directly to the **active site** — blocks the substrate from entering
- Can be overcome by **increasing substrate concentration** (substrates outcompete the inhibitor)
- V_{max} is unchanged (at very high $[\text{S}]$, all active sites are occupied by substrate)
- K_m **increases** (need more substrate to reach $\frac{1}{2}V_{\text{max}}$)

Non-competitive Inhibition:

- Inhibitor binds to a site **other than the active site** (allosteric site)
- Causes a **conformational change** in the enzyme that distorts the active site
- Substrate can still bind, but the reaction rate is reduced
- **Cannot** be overcome by increasing $[\text{S}]$
- V_{max} **decreases** (fewer functional enzyme molecules at any given time)
- K_m is unchanged (affinity for substrate is not affected)



Competitive vs non-competitive inhibition: effect on Michaelis-Menten kinetics

MEMORISE THIS

Inhibition summary:

Feature	Competitive	Non-competitive
Binds to	Active site	Allosteric site
Overcome by high $[\text{S}]$?	Yes	No
V_{max}	Unchanged	Decreased
K_m	Increased	Unchanged
Example	Malonate vs succinate (Krebs)	Heavy metals (Pb^{2+}, Hg^{2+})

1.5 Allosteric Regulation HL

AHL — C1.1

Some enzymes have a second binding site — separate from the active site — that acts like a volume knob for the whole pathway. When a small molecule binds there, it either speeds up or slows down the enzyme by changing its shape. This is how cells fine-tune their metabolism in real time without switching genes on or off.

Allosteric enzymes have **regulatory sites** separate from the active site. Binding of an effector molecule changes the enzyme's conformation:

- **Allosteric activators** stabilise the active conformation → increase activity
- **Allosteric inhibitors** stabilise the inactive conformation → decrease activity

End-product inhibition (negative feedback): The final product of a metabolic pathway inhibits the first enzyme in that pathway. This prevents overproduction and conserves resources.

$$A \xrightarrow{E_1} B \xrightarrow{E_2} C \xrightarrow{E_3} D$$

If D accumulates, it inhibits E_1 (allosteric inhibition). When D is used up, inhibition is released and the pathway resumes. This is a **self-regulating** system.

> **IB TIP**
>
> **IB Tip:** End-product inhibition is a classic 6-mark question topic. Always draw the pathway, label the enzymes, and show the feedback arrow from the final product to the first enzyme. State that this is **reversible** — the product dissociates from the allosteric site when its concentration drops.

MCQ Practice

An enzyme has a K_m of 2.5 mM. A competitive inhibitor is added. What is the most likely new K_m?

A. 1.0 mM

B. 2.5 mM

C. 5.0 mM ← CORRECT

D. The K_m cannot be determined without knowing $V_{\max}$

Why: Competitive inhibitors increase K_m because more substrate is needed to outcompete the inhibitor and reach $\frac{1}{2}V_{\max}$. The $V_{\max}$ itself is unchanged (at infinite $[\mathrm{S}]$, the substrate always wins). Option A describes increased affinity (wrong direction). Option B would mean no effect (that is the non-competitive pattern for K_m). Option D is a distractor — K_m is independent of $V_{\max}$.

MCQ Practice

A non-competitive inhibitor is added to an enzyme. Which graph correctly shows the effect?

A. V_{max} increases, K_m unchanged

B. V_{max} unchanged, K_m increases

C. V_{max} decreases, K_m unchanged ← CORRECT

D. Both V_{max} and K_m decrease

Why: Non-competitive inhibitors bind to an allosteric site and reduce the number of functional enzyme molecules, lowering V_{max}. Because the inhibitor does not compete with the substrate for the active site, K_m (a measure of substrate affinity) is unaffected. Option B describes competitive inhibition. Option A is physiologically nonsensical for an inhibitor.

▸Watch: Enzymes — Structure, Function & Inhibition VIDEO

Section 2: Cell Theory & Ultrastructure (A1.1 / A1.2)

2.1 Cell Theory

Cell theory has three main principles:

1. **All living organisms are composed of cells** (or cell products)
2. **Cells are the smallest unit of life** — they can carry out all functions of life
3. **All cells come from pre-existing cells** (no spontaneous generation)

MEMORISE THIS

Functions of life (MRS GREN or MRS C GREN):

Letter	Function
M	Movement
R	Respiration
S	Sensitivity (response to stimuli)
G	Growth
R	Reproduction
E	Excretion
N	Nutrition

EXAM ALERT

Exam Alert: Exceptions to cell theory are often tested:

- **Skeletal muscle fibres** — multinucleate (many nuclei, one continuous cytoplasm) — not typical single-nucleus cells
- **Giant algae** (*Acetabularia*) — single cell up to 10 cm long
- **Aseptate fungal hyphae** — continuous cytoplasm without dividing walls

These do NOT disprove cell theory — they are unusual cell types that are still composed of cells.

2.2 Prokaryotic vs Eukaryotic Cells

MEMORISE THIS

Key comparison:

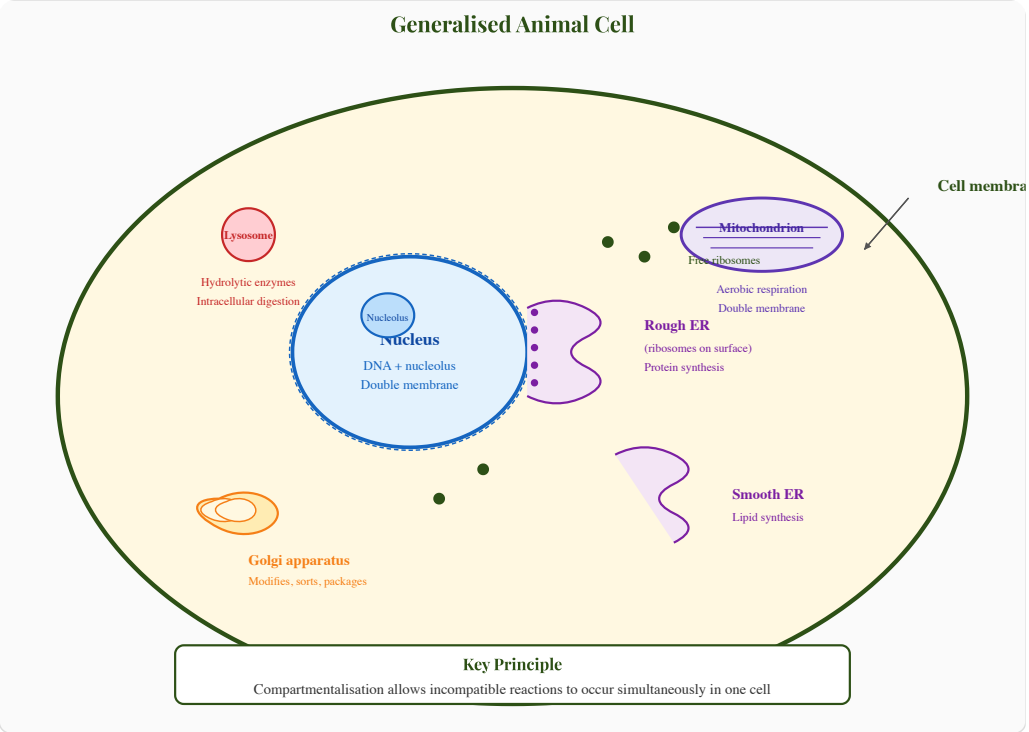
Feature	Prokaryote	Eukaryote
Nucleus	No true nucleus; nucleoid region	True nucleus with nuclear envelope
DNA	Circular, naked (no histones)	Linear, wrapped around histones
Ribosomes	70S (small)	80S (large); 70S in mitochondria/chloroplasts
Organelles	No membrane-bound organelles	Membrane-bound organelles (ER, Golgi, mitochondria)
Cell wall	Peptidoglycan (bacteria)	Cellulose (plants), chitin (fungi), none (animals)
Size	1-10 μm	10-100 μm
Plasmids	Present (small circular DNA)	Absent (usually)
Replication	Binary fission	Mitosis / Meiosis

IB TIP

IB Tip: The IB loves asking about **ribosome size**: 70S in prokaryotes and in mitochondria/chloroplasts (evidence for endosymbiotic theory), 80S in eukaryotic cytoplasm. Remember: S values are NOT additive (70S = 50S + 30S subunits, not 80S).

2.3 Eukaryotic Cell Ultrastructure HL

Ultrastructure refers to the internal architecture of a cell as revealed by an electron microscope — the organelles, membranes, and structures too small to see with light. Knowing each organelle's structure helps you understand its function, because the two are always matched: a large surface area for reactions, small volumes to build gradients, and compartments to keep incompatible processes separate.



Generalised animal cell showing key organelles and their functions

MEMORISE THIS

Organelle functions:

Organelle	Key function	Membrane
Nucleus	Contains DNA; controls cell activity; site of transcription	Double (nuclear envelope with pores)
Rough ER	Protein synthesis and transport (ribosomes on surface)	Single
Smooth ER	Lipid synthesis; detoxification; calcium storage	Single
Golgi apparatus	Modifies, sorts, and packages proteins into vesicles	Single (stacked cisternae)
Mitochondrion	Aerobic respiration (ATP production)	Double (inner membrane folded into cristae)
Lysosome	Intracellular digestion using hydrolytic enzymes	Single
Ribosome	Translation (mRNA → protein)	No membrane (RNA + protein complex)
Centrioles	Organise spindle fibres during cell division	No membrane
Cell membrane	Controls entry/exit of substances	Phospholipid bilayer

2.4 Endosymbiotic Theory HL

AHL — A1.2

Mitochondria and chloroplasts are thought to have evolved from free-living prokaryotes that were engulfed by ancestral eukaryotic cells. Evidence:

- **Double membrane** — inner membrane from the prokaryote, outer from the host's vesicle
- **Own DNA** — circular, like bacterial DNA
- **Own ribosomes** — 70S (prokaryotic size), not 80S
- **Binary fission** — divide independently of the host cell
- **Size** — similar to bacteria (~1-10 μm)

⚠ EXAM ALERT

Exam Alert: The IB frequently asks: "Outline evidence for the endosymbiotic theory." You need at least **three** pieces of evidence. The most commonly tested are: double membrane, circular DNA, and 70S ribosomes. Do NOT say "they have their own nucleus" — they do NOT have a nucleus.

MCQ Practice

Which of the following is evidence for the endosymbiotic origin of mitochondria?

A. Mitochondria have 80S ribosomes like the cytoplasm

B. Mitochondria have circular DNA and 70S ribosomes ← CORRECT

C. Mitochondria are surrounded by a single membrane

D. Mitochondria cannot replicate independently

Why: Mitochondria have circular DNA (like bacteria), 70S ribosomes (like bacteria), and divide by binary fission (like bacteria). They have a DOUBLE membrane (not single). They CAN replicate semi-independently. 80S ribosomes are found in the eukaryotic cytoplasm, not inside mitochondria.

MCQ Practice

A student observes a cell under an electron microscope. The cell has no nucleus but contains ribosomes and a cell wall made of peptidoglycan. Which organism does this cell most likely belong to?

A. A plant

B. A fungus

C. A bacterium ← CORRECT

D. An animal

Why: No nucleus = prokaryote. Peptidoglycan cell wall = bacterium (not archaea, which have different cell wall composition). Plants have cellulose walls, fungi have

chitin walls, and animals have no cell wall. The presence of ribosomes is universal and does not distinguish cell types.

Section 3: Membrane Structure & Transport (A1.2)

The cell membrane is not just a passive barrier — it is a dynamic, selective gateway that controls everything entering and leaving the cell. Understanding its structure explains why some substances cross freely while others need help, and why cells can maintain internal conditions completely different from the surrounding environment.

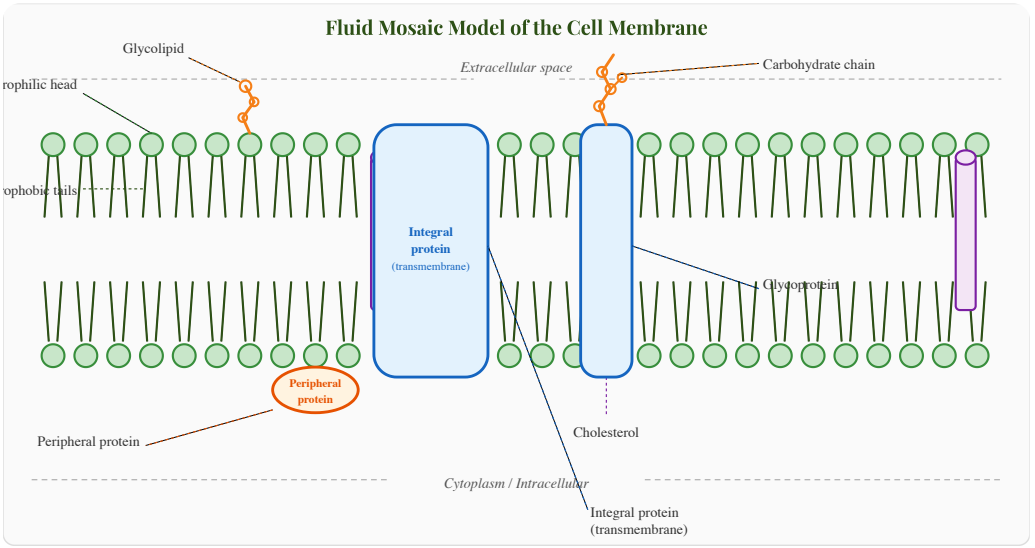
3.1 The Fluid Mosaic Model

The cell membrane is described by the **fluid mosaic model** (Singer-Nicolson, 1972):

- **Fluid** — phospholipids and proteins can move laterally within the bilayer
- **Mosaic** — proteins are scattered throughout, like tiles in a mosaic

Components:

- **Phospholipid bilayer** — hydrophilic heads face outward, hydrophobic tails face inward
- **Integral proteins** — span the entire membrane (transmembrane); involved in transport
- **Peripheral proteins** — attached to one surface; often enzymes or structural
- **Cholesterol** — embedded between phospholipids; regulates fluidity
- **Glycoproteins** — cell recognition and signalling
- **Glycolipids** — cell recognition



Fluid mosaic model: the cell membrane is a dynamic phospholipid bilayer with embedded proteins, cholesterol, and glycoproteins/glycolipids

> **IB TIP**
>
> **IB Tip:** Cholesterol makes the membrane LESS fluid at high temperatures (restricts phospholipid movement) and MORE fluid at low temperatures (prevents tight

packing). It acts as a **fluidity buffer**. This is commonly tested.

3.2 Transport Across Membranes

Cells need to move substances in and out constantly — nutrients in, waste out, signals received and sent. Some substances can slip through the membrane on their own; others need protein channels or pumps. Whether a cell spends ATP on this depends on whether the substance is moving with or against its concentration gradient.

Type	Direction	Energy?	Examples
Simple diffusion	High → low concentration	No (passive)	O_2, CO_2, steroid hormones
Facilitated diffusion	High → low concentration	No (passive)	Glucose (via channel/carrier proteins)
Osmosis	High water potential → low water potential	No (passive)	Water across membranes
Active transport	Low → high concentration	Yes (ATP)	Na^+/K^+ pump, mineral uptake in roots
Endocytosis	Into cell	Yes (ATP)	Phagocytosis, pinocytosis
Exocytosis	Out of cell	Yes (ATP)	Secretion of hormones, neurotransmitters

⚠ EXAM ALERT

Exam Alert: Facilitated diffusion is PASSIVE — it does NOT require ATP. It uses channel proteins or carrier proteins but still moves DOWN the concentration gradient. Active transport moves AGAINST the gradient and REQUIRES ATP. Students often confuse facilitated diffusion with active transport because both use proteins.

MCQ Practice

Which statement correctly describes osmosis?

A. The movement of solute molecules from high to low concentration

B. The active transport of water using ATP

C. The net movement of water from a region of higher water potential to lower water potential through a partially permeable membrane ← CORRECT

D. The diffusion of water from low solute concentration to high solute concentration without a membrane

Why: Osmosis specifically refers to water movement through a partially permeable membrane, driven by water potential differences. It is passive (no ATP). Option A describes diffusion of solutes. Option D removes the membrane requirement, which is essential to the definition of osmosis.

Section 4: Cell Division (D1.1)

4.1 The Cell Cycle

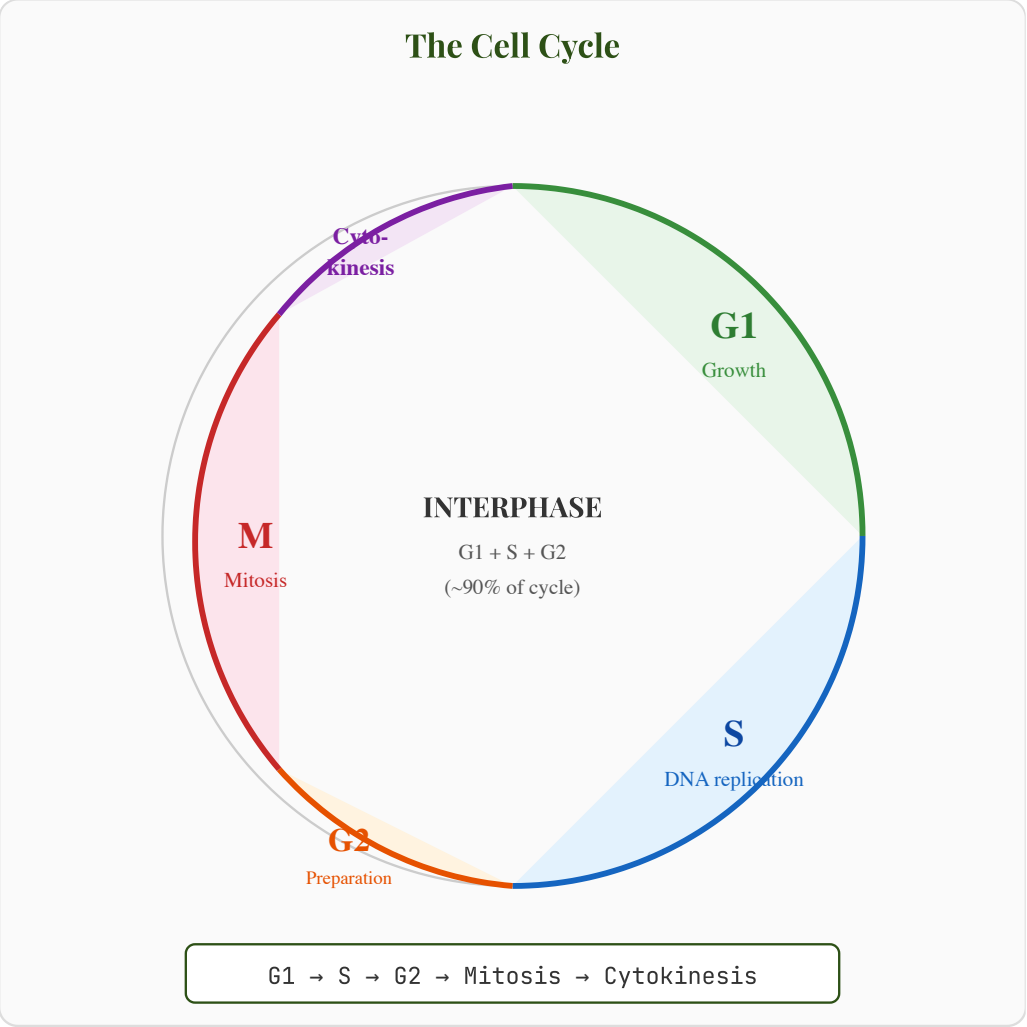
The cell cycle consists of **interphase** and **mitotic phase (M phase)**:

Interphase (longest phase, ~90% of cycle time):

- G_1 **phase** — cell grows, organelles replicate, proteins synthesised
- S **phase** — DNA replication (each chromosome → two sister chromatids joined at centromere)
- G_2 **phase** — cell prepares for division; centrioles replicate; final checks

M phase:

- **Mitosis** — nuclear division (PMAT: Prophase, Metaphase, Anaphase, Telophase)
- **Cytokinesis** — cytoplasmic division



The cell cycle: interphase (G1, S, G2) and M phase (mitosis + cytokinesis)

4.2 Mitosis — Stages

MEMORISE THIS

Remember PMAT:

Stage	Events	Key feature
Prophase	Chromosomes condense and become visible; nuclear envelope begins to break down; spindle fibres form from centrioles	Chromosomes appear as sister chromatids joined at centromere
Metaphase	Chromosomes align at the **metaphase plate** (cell equator); spindle fibres attach to centromeres	Chromosomes in a line at the middle
Anaphase	Centromeres split; sister chromatids pulled to opposite poles by shortening spindle fibres	Chromatids move apart (V-shape)
Telophase	Chromatids arrive at poles; nuclear envelopes reform; chromosomes decondense; spindle disassembles	Two nuclei visible
Cytokinesis	Cytoplasm divides: cleavage furrow (animals) or cell plate (plants)	Two identical daughter cells

EXAM ALERT

Exam Alert: Mitosis produces **two genetically identical daughter cells** with the SAME chromosome number as the parent (diploid → diploid). This is fundamentally different from meiosis, which produces four genetically different haploid cells. The IB will test this distinction repeatedly.

WORKED EXAMPLE

Worked Example: Chromosome Counting

A human somatic cell has 46 chromosomes ($2n = 46$).

- After S **phase**: still 46 chromosomes, but each now consists of 2 sister chromatids (92 chromatids total, but still counted as 46 chromosomes because they are joined at the centromere)
- After **anaphase**: 92 chromatids are separated → become 92 individual chromosomes (46 moving to each pole)
- After **telophase + cytokinesis**: each daughter cell has 46 chromosomes (back to normal)

Key rule: A chromosome is counted by its centromere. As long as two chromatids share one centromere, they are ONE chromosome.

4.3 Mitosis vs Meiosis HL

Feature	Mitosis	Meiosis
Divisions	1	2 (meiosis I + meiosis II)
Daughter cells	2 identical	4 genetically different
Chromosome number	Same as parent (diploid → diploid)	Halved (diploid → haploid)
Crossing over	No	Yes (prophase I)
Independent assortment	No	Yes (metaphase I)
Purpose	Growth, repair	Production of gametes
Where	Somatic cells	Gonads (ovaries, testes)
Genetic variation	None	Significant (crossing over + independent assortment)

> **IB TIP**
>
> **IB Tip:** The sources of genetic variation in meiosis are: (1) **crossing over** in prophase I — exchange of alleles between homologous chromosomes, and (2) **independent assortment** in metaphase I — random orientation of homologous pairs. Plus (3) **random fertilisation** adds further variation. State all three for full marks.

MCQ Practice

A cell with 8 chromosomes undergoes mitosis. How many chromosomes will be in each daughter cell?

A. 4

B. 8 ← CORRECT

C. 16

D. 2

Why: Mitosis produces daughter cells with the SAME number of chromosomes as the parent cell. The DNA is replicated in S phase, sister chromatids are separated, and each daughter cell receives a complete set. Meiosis would halve the number (to 4), but the question specifies mitosis.

MCQ Practice

During which stage of mitosis do the centromeres split?

A. Prophase

B. Metaphase

C. Anaphase ← CORRECT

D. Telophase

Why: Centromeres split during anaphase, allowing sister chromatids to be pulled to opposite poles by shortening spindle fibres. In prophase, chromosomes condense. In metaphase, they align. In telophase, nuclear envelopes reform.

Section 5: HL Extension — Enzyme Kinetics & Metabolic Pathways HL

5.1 Metabolic Pathways

Metabolism is a web of interconnected enzyme-catalysed reactions. Pathways can be:

- **Linear**: $A \rightarrow B \rightarrow C \rightarrow D$
- **Branched**: Product C can feed into two different pathways
- **Cyclic**: Like the Krebs cycle — the starting molecule is regenerated

Each step in a pathway is catalysed by a specific enzyme. The product of one reaction becomes the substrate for the next. This is called **metabolic channelling**.

5.2 Cofactors and Coenzymes

- **Cofactor**: Non-protein molecule required for an enzyme to function. Can be inorganic ions (Mg^{2+}, Fe^{2+}, Zn^{2+}) or organic molecules (coenzymes)
- **Coenzyme**: Organic cofactor, often derived from vitamins. Examples:
  - NAD^+ (from vitamin B3 / niacin) — electron carrier in respiration
  - FAD (from vitamin B2 / riboflavin) — electron carrier in Krebs cycle
  - Coenzyme A (from vitamin B5) — carries acetyl groups

> **IB TIP**
>
> **IB Tip:** When the IB asks "Explain why vitamins are essential in the diet," the answer is: vitamins are precursors for coenzymes, which are required for enzyme function. Without the vitamin, the coenzyme cannot be made, and the enzyme-catalysed reaction cannot proceed at a sufficient rate.

5.3 Immobilised Enzymes HL

AHL — C1.1

Enzymes can be fixed (immobilised) to an inert support material. Methods include:

- **Gel entrapment** — enzyme trapped in alginate or polyacrylamide beads
- **Adsorption** — enzyme bound to surface of glass beads or activated carbon
- **Covalent bonding** — enzyme chemically bonded to a support

Advantages of immobilisation:

- Enzyme can be **reused** (reduced cost)
- Product is **not contaminated** with enzyme

- Enzyme is more **thermostable** (restricted movement reduces denaturation)
- Continuous production in **column reactors**

Disadvantages:

- Immobilisation can **reduce activity** (active site may be blocked or distorted)
- Diffusion of substrate to active site may be slower

MCQ Practice

Which of the following is an advantage of using immobilised enzymes in industrial processes?

A. The enzyme works faster because it is trapped in a gel

B. The products are always purer because no reaction occurs

C. The enzyme can be recovered and reused, reducing costs ← CORRECT

D. Immobilised enzymes never denature at any temperature

Why: The primary industrial advantage of immobilisation is enzyme reuse. The enzyme is fixed in place, so it can be separated from the product easily. Option A is false — immobilisation can actually slow the reaction due to diffusion limitations. Option D is false — immobilised enzymes are more thermostable but will still denature at extreme temperatures.

MCQ Practice

Which row correctly matches the cofactor with its enzyme or process?

	Cofactor	Process
A	Zn^{2+}	Photolysis of water
B	NAD^{+}	**Oxidation reactions in respiration**
C	Ca^{2+}	Calvin cycle
D	Mg^{2+}	Electron transport chain

B is CORRECT ← CORRECT

Why: NAD^{+} is the primary electron carrier in cell respiration, accepting hydrogen atoms during oxidation reactions (glycolysis, link reaction, Krebs cycle). Zn^{2+} is a cofactor for carbonic anhydrase, not photolysis. Ca^{2+} is involved in muscle contraction and signalling, not the Calvin cycle. Mg^{2+} is actually a cofactor for RuBisCO and is part of chlorophyll, not the ETC.

Section 6: Exam Strategy & Common Mistakes

Top 10 Enzyme & Cell Biology Mistakes

1. Saying enzymes "provide energy" — they lower E_a, not provide energy
2. Confusing denaturation with inactivation at low temperature
3. Saying non-competitive inhibitors bind to the active site
4. Forgetting that K_m INCREASES with competitive inhibition
5. Saying mitochondria have 80S ribosomes — they have 70S
6. Confusing "cell wall" and "cell membrane" — plants have BOTH
7. Saying mitosis produces haploid cells — that is meiosis
8. Forgetting that DNA replication occurs in S phase, NOT in mitosis
9. Saying osmosis is "movement of water from low to high concentration" without specifying water potential and membrane
10. Saying crossing over occurs in mitosis — it occurs only in meiosis (prophase I)

> **IB TIP**
>
> **IB Tip:** For Paper 1 (MCQ), process of elimination is your best tool. Cross out answers that contain common misconceptions listed above. Usually 2 of the 4 options will contain obvious errors if you know the top mistakes.

MCQ Practice

Which statement about enzymes is correct?

A. Enzymes increase the activation energy of a reaction

B. Enzymes change the equilibrium position of a reaction

C. Enzymes are specific to their substrates due to the shape of the active site ← CORRECT

D. Enzymes are consumed during the reaction and must be resynthesised

Why: Enzymes are specific because the active site is complementary in shape (and charge) to the substrate. Option A is backwards — enzymes DECREASE E_a. Option B is false — enzymes speed up the rate of reaching equilibrium but do not change the equilibrium position itself. Option D is false — enzymes are catalysts and are recycled (not consumed).

MCQ Practice

A cell is placed in a hypertonic solution. Which of the following will occur?

A. The cell will swell and may lyse

B. Water will enter the cell by osmosis

C. Water will leave the cell by osmosis, and the cell will shrink ← CORRECT

D. There will be no net movement of water

Why: In a hypertonic solution, the solute concentration outside is higher than inside (water potential is lower outside). Water moves from higher water potential (inside the cell) to lower water potential (outside) by osmosis. The cell loses water and shrinks (crenation in animal cells, plasmolysis in plant cells). Option A describes what happens in a hypotonic solution.

Section 7: Integration — Linking Enzymes to Metabolism

Why Enzymes Matter for Everything

Every metabolic pathway you study in IB Biology depends on enzymes:

Pathway	Key enzyme(s)	Topic
Glycolysis	Hexokinase, phosphofructokinase	C1.2
Krebs cycle	Isocitrate dehydrogenase	C1.2
Photosynthesis	RuBisCO, ATP synthase	C1.3
DNA replication	DNA helicase, DNA polymerase, ligase	D1.2
Transcription	RNA polymerase	D1.2
Translation	Peptidyl transferase (ribosomal)	D1.2
Digestion	Amylase, pepsin, lipase	D1.1

MEMORISE THIS

Key enzyme to remember: RuBisCO (ribulose bisphosphate carboxylase/oxygenase)

- Most abundant enzyme on Earth
- Catalyses carbon fixation in the Calvin cycle: $CO_2 + \text{RuBP} \rightarrow 2 \times \text{GP}$
- Can also fix O_2 instead of CO_2 (photorespiration) — this is wasteful
- Why? Because RuBisCO evolved when there was little O_2 in the atmosphere

MCQ Practice

Phosphofructokinase (PFK) is inhibited by ATP and activated by AMP. This is an example of:

A. Competitive inhibition by ATP

B. Denaturation of PFK by ATP

C. Allosteric regulation by end-product inhibition ← CORRECT

D. Non-competitive inhibition that permanently inactivates PFK

Why: PFK is an allosteric enzyme. ATP (the end product of respiration) inhibits PFK by binding to an allosteric site, slowing glycolysis when energy is plentiful. AMP (indicating low energy) activates PFK. This is a classic example of end-product (feedback) inhibition — reversible, not permanent. It is NOT competitive because ATP does not bind to the active site (the active site binds fructose-6-phosphate).

IB Exam-Style Questions

Question 1 *(3 marks)*

Explain how the structure of an enzyme's active site accounts for its specificity for a particular substrate.

▶ Markscheme

Question 2 *(4 marks)*

Describe the effect of increasing temperature on enzyme activity. Explain the changes observed at temperatures below and above the optimum.

▶ Markscheme

Question 3 *(4 marks)*

Distinguish between competitive inhibition and non-competitive inhibition of enzymes.

▶ Markscheme

Question 4 *(3 marks)*

A student observes a cell organelle under an electron micrograph. The organelle has a double membrane, an extensively folded inner membrane (cristae), and a dense matrix. State the identity of this organelle and give two structural features visible in the description that support this identification.

▶ Markscheme

Mixed Practice — Exam Style

> **IB TIP**
>
> **How to use this section:** Unlike topic-specific practice, these questions are interleaved — they mix all topics from this guide in random order. Before answering, identify *which concept or topic area* the question is testing. This is exactly the skill you need on Paper 1 and Paper 2, where you don't know in advance which topic each question covers.

1. **[Enzyme Kinetics]** At very high substrate concentrations, the rate of an enzyme-catalysed reaction plateaus. The best explanation is:

   A. The enzyme is denatured by excess substrate

   B. All active sites are occupied (enzymes are saturated), so adding more substrate has no effect on rate

   C. The substrate begins to inhibit the enzyme competitively at high concentrations

   D. High substrate concentrations lower the pH, reducing enzyme activity

2. **[Cell Membrane Structure]** The fluid mosaic model describes the plasma membrane as:

   A. A rigid bilayer of phospholipids with proteins embedded at fixed positions

   B. A fluid phospholipid bilayer in which proteins can move laterally, with the hydrophilic heads facing inward and hydrophobic tails facing outward

   C. A fluid phospholipid bilayer with hydrophilic heads facing the aqueous environment and hydrophobic tails facing the interior of the bilayer; proteins are embedded or associated with this structure

   D. A single layer of glycoproteins embedded in a lipid monolayer

3. **[Inhibition Types]** An inhibitor reduces enzyme activity. Increasing substrate concentration fully restores the original maximum reaction rate ($V_{\max}$). This inhibitor is best described as:

   A. Non-competitive

   B. Irreversible

   C. Allosteric (activating)

   D. Competitive

4. **[Cell Division — Mitosis]** During which phase of mitosis do sister chromatids separate and move to opposite poles?

   A. Prophase

   B. Metaphase

   C. Anaphase

   D. Telophase

5. **[Transport Mechanisms]** A large polar molecule cannot cross the phospholipid bilayer by simple diffusion. The most likely mechanism by which it crosses the

membrane is:

A. Osmosis through aquaporins

B. Facilitated diffusion through a specific channel or carrier protein, moving down its concentration gradient without ATP

C. Active transport using a pump protein, requiring ATP

D. Endocytosis, regardless of the molecule's size

6. **[Enzyme Kinetics — Distractor]** A student heats an enzyme solution to 80°C for 10 minutes and then returns it to 37°C. They observe no enzyme activity. The most accurate explanation is:

   A. The enzyme is still inhibited by the high temperature even after cooling

   B. The enzyme has been permanently denatured — its tertiary structure has been disrupted, changing the shape of the active site so that substrate can no longer bind

   C. The enzyme has been competitively inhibited by heat

   D. The enzyme has been reversibly inhibited; activity will return after several hours at 37°C

7. **[Cell Membrane — Transport]** Sodium ions (Na^+) are maintained at a higher concentration outside the cell than inside. The sodium-potassium pump moves Na^+ out of the cell against this gradient. This is an example of:

   A. Facilitated diffusion — no energy required because ions use a protein channel

   B. Active transport — energy (ATP) is required to move ions against their concentration gradient

   C. Osmosis — water follows the sodium ions

   D. Passive transport — the gradient drives the movement

8. **[Allosteric Regulation — Distractor]** Phosphofructokinase (PFK) is inhibited by high ATP concentrations. A student claims this is competitive inhibition because ATP is also a substrate for PFK. Evaluate this claim:

   A. Correct — ATP binds to the active site as both a substrate and an inhibitor

   B. Incorrect — ATP as an inhibitor binds to an allosteric (regulatory) site, not the active site; this is allosteric/non-competitive inhibition, not competitive inhibition

C. Correct — increasing substrate (fructose-6-phosphate) concentration would not restore activity

D. Incorrect — PFK is not regulated by ATP at all

9. **[Cell Division — Meiosis vs Mitosis]** Which of the following is unique to meiosis and does NOT occur in mitosis?

   A. Chromosome condensation in prophase

   B. Spindle fibre formation and attachment to centromeres

   C. Homologous chromosomes pairing (synapsis) and crossing over in prophase I

   D. Sister chromatids separating at the centromere

10. **[Enzyme Kinetics — Michaelis Constant]** The Michaelis constant K_m is defined as the substrate concentration at which reaction rate is half of $V_{\max}$. A low K_m indicates:

    A. The enzyme has a low affinity for its substrate — it requires a high substrate concentration to function

    B. The enzyme has a high affinity for its substrate — it reaches half-maximal rate at a low substrate concentration

    C. The enzyme has a low maximum velocity and is not efficient

    D. The enzyme is more likely to be allosteric

▶ Show Answers

IB Biology HL — Enzymes & Cell Biology — Complete Study Guide — 2025 Syllabus — Good luck!

May 2026 Prediction Questions

> ⚠ EXAM ALERT
>
> **These are NOT official IB questions.** These are trend-based practice questions written to reflect the topic areas and question styles most likely to appear on the May 2026 IB Biology HL Paper 2. Based on recent exam patterns (2022-2025), expect heavy weighting on: Michaelis-Menten kinetics, competitive vs non-competitive inhibition, enzyme denaturation, and factors affecting enzyme activity.

WORKED EXAMPLE

Question 1 [Michaelis-Menten Kinetics] [~7 marks]

The enzyme lactase catalyses the hydrolysis of lactose into glucose and galactose. An experiment measures the initial reaction rate (v) at different substrate concentrations ([S]) with a fixed enzyme concentration.

(a) Sketch a Michaelis-Menten curve for this reaction. Label $V_{\max}$ and K_m on your graph.

(b) Define K_m and explain its biological significance.

(c) A second experiment uses half the original enzyme concentration. On the same axes, sketch the expected curve and explain the changes to $V_{\max}$ and K_m.

▶ Show Solution

WORKED EXAMPLE

Question 2 [Enzyme Inhibition] [~7 marks]

The diagram below shows the effect of two different inhibitors (X and Y) on the rate of an enzyme-catalysed reaction at varying substrate concentrations. Without any inhibitor, the enzyme has $V_{\max} = 120\,\mu\text{mol min}^{-1}$ and $K_m = 4\,\text{mM}$.

- **Inhibitor X:** $V_{\max}$ remains 120, but the apparent K_m increases to 8 mM.
- **Inhibitor Y:** $V_{\max}$ decreases to 60, and K_m remains 4 mM.

(a) Identify the type of inhibition caused by Inhibitor X and Inhibitor Y.

(b) Explain the molecular mechanism of each type of inhibition.

(c) For Inhibitor X, explain why increasing substrate concentration can overcome the inhibition.

▶ Show Solution

WORKED EXAMPLE

Question 3 [Denaturation] [~6 marks]

An experiment measures the activity of the enzyme catalase at temperatures ranging from 10 °C to 80 °C.

(a) Sketch a graph of enzyme activity against temperature for catalase. Label the optimum temperature.

(b) Explain the shape of the graph above the optimum temperature in terms of protein structure.

(c) Distinguish between denaturation and competitive inhibition in terms of their reversibility and effect on enzyme structure.

▶ Show Solution

Virtual Lab Alignment: Labster Simulations

IB TIP

Using Labster in IB Biology? The simulations below map directly to IB Biology HL syllabus topics covered in this guide. Use them before your internal assessments (IAs) or to build intuition for experimental questions in Paper 3.

Labster Simulation	IB HL Topic	What It Covers
Enzyme Kinetics: Unravel the Effect of Substrate Concentration	B4/C3: Michaelis-Menten kinetics	V_{max}, competitive vs non-competitive inhibition
Enzyme Kinetics: Investigate the Effect of Temperature and pH	B4/C3: Lock-and-key vs induced fit	Denaturation, optimum conditions
Protein Folding: Alphafold's Revolution	B2/C3: Protein structure	Primary to quaternary structure, active site, allosteric regulation
Lactase: The Science Behind Lactose-Free Products	B4/C3: Applied enzyme activity	Industrial enzymes, real-world IB context

How to use these simulations for IB exam prep:

- Enzyme Kinetics simulations generate rate vs. substrate concentration graphs — practice interpreting these for Paper 3 data analysis
- The Lactase simulation is explicitly cited by Labster as aligned to AP Biology and IB Biology — it is a strong IA context too
- The Protein Folding simulation builds conceptual understanding of active site shape and why denaturation is irreversible