

IB Biology HL Photosynthesis & Respiration: Complete Guide 2026

IB HL Study Guide

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Virtual Lab Alignment: Labster Simulations

💡 IB TIP

Quick Reference:

- **Syllabus Topics:** C1.2 Cell Respiration · C1.3 Photosynthesis
- **Key Processes:** Photosynthesis (light-dependent reactions, Calvin cycle), cellular respiration (glycolysis, Krebs cycle, electron transport chain)
- **Exam Focus:** Process locations (cytoplasm, mitochondrial matrix, inner membrane, thylakoid, stroma), chemiosmosis, ATP yield, photolysis of water, NADH/FADH₂ carriers
- **Common Questions:** Where does glycolysis occur? Where is the Krebs cycle? What is the overall equation for photosynthesis? Explain chemiosmosis in chloroplasts vs mitochondria
- **HL-Only Content:** Chloroplast adaptations, photosystems and pigment arrays, cyclic vs non-cyclic photophosphorylation, detailed Calvin cycle mechanism, limiting factors analysis

How to Use This Guide

- **Photosynthesis** — all light reactions, Calvin cycle, HL detail
- **Cellular Respiration** — glycolysis, Krebs, ETC, chemiosmosis
- **HL / AHL Only** — extra depth required at Higher Level
- **MCQ Practice** — styled like real IB Paper 1 questions
- **Exam Alerts** — the traps and mistakes that cost marks

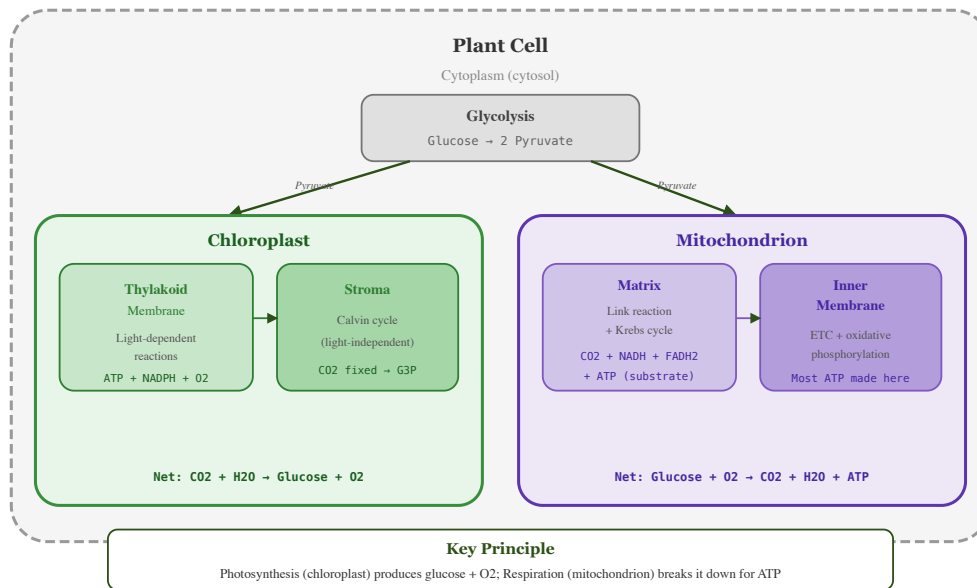
Aigned to IB Biology 2025 syllabus — C1.2 Cell Respiration — C1.3 Photosynthesis

Videos on this page: Photosynthesis & Respiration Overview · Light Reactions & Calvin Cycle · Cellular Respiration — Glycolysis, Krebs, ETC

Section 1: The Big Picture

Before any detail, you must understand **where** each process happens inside the cell. The single most common source of lost marks in MCQs is **confusing locations**. Fix this first and many questions become easy.

Cell Map — Where Every Reaction Occurs



Cell Map — where every reaction occurs in a plant cell

MEMORISE THIS

Memorise this table:

Process	Location
Glycolysis	Cytoplasm
Link Reaction	Mitochondrial matrix
Krebs Cycle	Mitochondrial matrix
ETC + ATP synthase	Inner mitochondrial membrane
Light reactions	Thylakoid membrane
Calvin cycle	Stroma (inside chloroplast)

EXAM ALERT

Common Mistakes:

- **Location confusion:** Glycolysis occurs in the **cytoplasm** (not in the mitochondria), while the Krebs cycle occurs in the **mitochondrial matrix** (not the cytoplasm or inner membrane). Know exactly where each process happens — these location swaps appear in nearly every MCQ paper.
- **Thylakoid vs stroma:** Light-dependent reactions occur on the **thylakoid membrane** (not in the stroma). The Calvin cycle occurs in the **stroma** (not on the thylakoid membrane). The membrane is where photosystems and ATP synthase sit; the stroma is the fluid space where CO₂ fixation happens.
- **Oxygen source:** The O₂ released during photosynthesis comes from **photolysis of H₂O** (splitting water on the thylakoid membrane), NOT from the Calvin cycle or from CO₂. Photolysis occurs at Photosystem II during the light-dependent reactions.

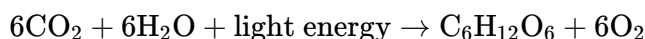
EXAM ALERT

Exam Alert: Krebs cycle is in the **MATRIX**, not the inner membrane. ETC is on the **INNER MEMBRANE**. These two are swapped in almost every wrong MCQ answer. The matrix is the fluid; the inner membrane is the physical structure where ETC proteins sit.

Overall Equations

The two processes are the **INVERSE** of each other.

Photosynthesis:



- O_2 comes from splitting H_2O (photolysis) — NOT from CO_2
- CO_2 is **FIXED** into glucose — it is a **REACTANT**

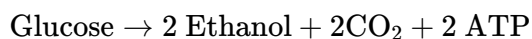
Aerobic Cellular Respiration:



Anaerobic — animals:



Anaerobic — yeast:



IB TIP

The Link: Products of photosynthesis (glucose, O_2) are the reactants of respiration — and vice versa (CO_2 , H_2O). These two processes drive the carbon and oxygen cycles on Earth.

MCQ Practice

Which statement is correct about the oxygen released during photosynthesis?

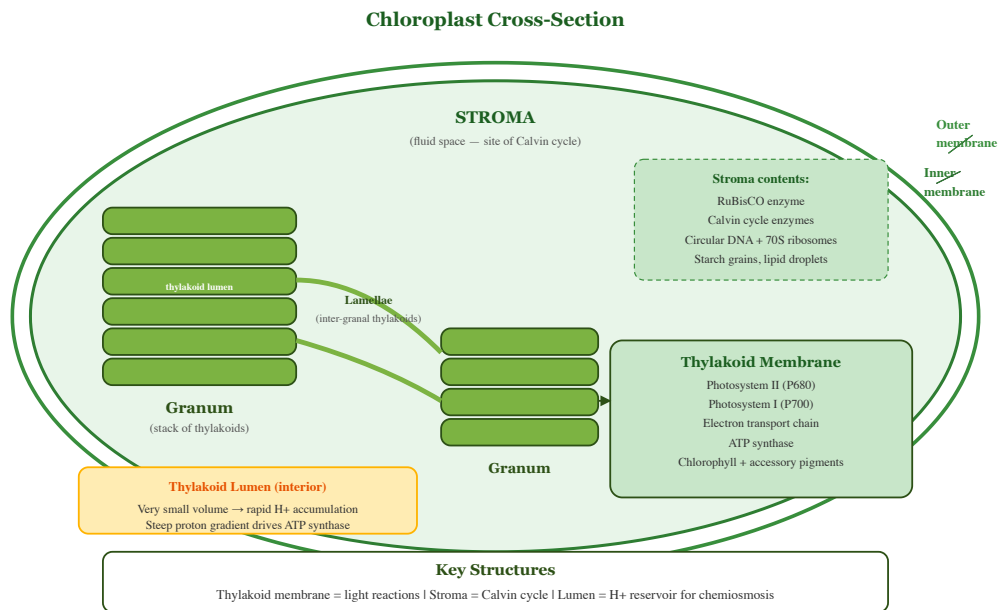
- A. It is produced when CO_2 is broken down in the stroma
- B. It is a by-product of the Calvin cycle
- C. It comes from the photolysis of water in the thylakoid ← CORRECT**
- D. It is produced when NADPH is oxidised

Why: O_2 is released during **PHOTOLYSIS** — the splitting of water molecules on the thylakoid membrane using light energy. CO_2 is fixed (incorporated) during the Calvin cycle; it does not release O_2 . This is one of the most frequently tested facts in photosynthesis MCQs.

Section 2: Photosynthesis

Photosynthesis converts **light energy into chemical energy** (stored in glucose). Two main stages: **Light-dependent reactions** on the thylakoid membrane, and the **Calvin cycle** in the stroma. Both stages must be understood in detail for HL.

2.1 Chloroplast Structure



Chloroplast Structure — cross-section with labelled compartments

Chloroplast Adaptations HL

AHL — B2.2.5

Thylakoid membrane — large surface area:

- Gives maximum space for photosystems, electron carriers, and ATP synthase
- Grana (stacked) greatly multiply the surface area per chloroplast

Thylakoid lumen — small volume:

- H⁺ ions pumped in by ETC quickly build up a steep concentration gradient
- A steep gradient = strong proton motive force = more efficient ATP synthesis
- Small volume means the same number of H⁺ ions creates a higher concentration

Stroma — compartmentalises Calvin cycle:

- Keeps RuBisCO and substrates (RuBP, CO₂) in high concentrations together

- Physically separate from cytoplasm — unique chemical environment maintained
- CO₂ diffuses directly from stomata into the stroma

Double membrane (envelope):

- Maintains a controlled internal environment
- Acts as a selective barrier — regulates what enters/exits the chloroplast

2.2 Photosynthetic Pigments and Light Absorption

Pigments absorb **specific wavelengths** of light. When a photon of the right wavelength hits a pigment, it **excites an electron** to a higher energy level. This energy drives the light reactions. Multiple pigments capture a **broad range** of wavelengths, increasing efficiency.

Absorption and Action Spectra

IB TIP

Key Point: The action spectrum closely **matches** the absorption spectrum. This is evidence that light absorption **causes** photosynthesis. Peaks occur at blue (~430 nm) and red (~680 nm).

Pigment	Wavelengths Absorbed / Role
Chlorophyll a	Red (680 nm) + blue-violet (430 nm). Main reaction-centre pigment. P680 in PS II, P700 in PS I
Chlorophyll b	Blue (450 nm) + orange-red. Accessory pigment — absorbs and transfers energy to Chl a
Carotenoids	Blue-violet (400-500 nm). Accessory pigments. Reflect yellow-orange wavelengths. Also protect chlorophyll from excess light damage
Phycocyanin / Phycoerythrin	Green and yellow (in algae/cyanobacteria). Fill the absorption gaps of chlorophylls

Photosystems and Pigment Arrays HL

AHL — C1.3.5

Antenna complex:

- Hundreds of accessory pigment molecules arranged around each reaction centre
- Absorb photons of various wavelengths and pass energy by resonance to the reaction centre
- Acts like a funnel — greatly increases the effective area for light capture
- Accessory pigments can NOT pass electrons directly to the ETC

Reaction centre (one special pair of chlorophyll a):

- **PS II reaction centre = P680** (absorbs 680 nm red light)
 - P680 donates an excited electron to the electron transport chain
 - $P680^+$ is the strongest biological oxidising agent (strong enough to split water)
- **PS I reaction centre = P700** (absorbs 700 nm far-red light)
 - Re-energises electrons received from PS II
 - Passes electrons to ferredoxin, which ultimately reduces $NADP^+$

EXAM ALERT

Important: PS II comes FIRST in the electron flow (despite the lower number!).

Flow: $H_2O \rightarrow PS II \rightarrow ETC \rightarrow PS I \rightarrow NADP^+$

MCQ Practice

Which of the following correctly describes a photosystem's antenna complex?

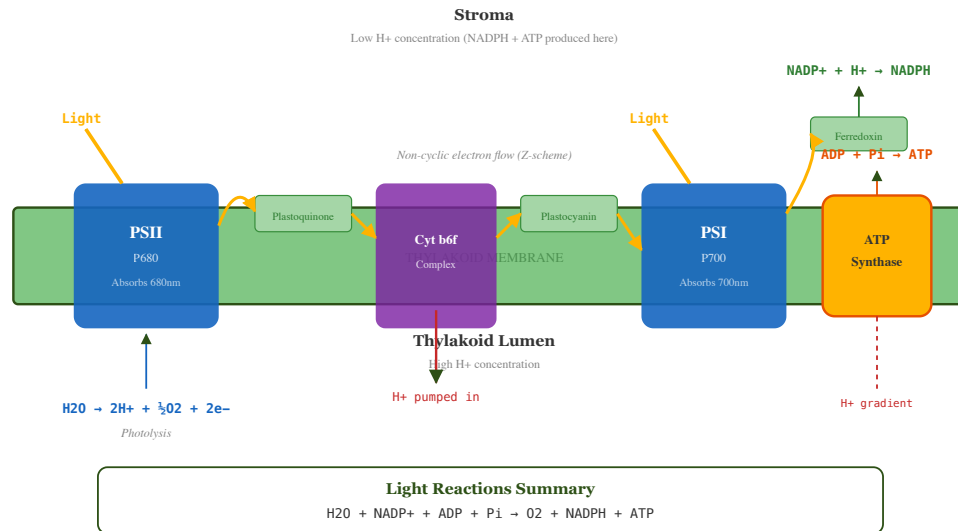
- A. A single chlorophyll a molecule that absorbs red light only
- B. An array of accessory pigments that absorb light and pass energy to the reaction centre ← CORRECT**
- C. The site where water is split to release oxygen
- D. A protein complex that pumps H^+ across the thylakoid membrane

Why: The antenna complex is an array of many accessory pigment molecules that absorb light of various wavelengths and transfer the energy by resonance to the reaction centre. Water is split at the reaction centre of PS II (not the antenna). H^+ pumping is done by the cytochrome b6f complex in the ETC.

2.3 Light-Dependent Reactions

The light-dependent reactions occur on the **thylakoid membrane**. They produce ATP, NADPH, and O_2 — the O_2 is a waste product. Two types: **non-cyclic photophosphorylation** (both PS I and PS II) and **cyclic photophosphorylation** (PS I only).

Non-Cyclic Photophosphorylation — The Z-Scheme



Light-Dependent Reactions — thylakoid membrane

Photolysis is the splitting of water molecules using light energy — it is what produces the oxygen released during photosynthesis and replenishes the electrons lost by PS II. Without photolysis, the light reactions would run out of electrons and stop.

Non-cyclic products: ATP + NADPH + O₂

Electron source: H₂O (split by photolysis at PS II)

Electron destination: NADPH (electrons carried out of light reactions)

Cyclic Photophosphorylation (PS I Only)

Electron path: PS I → Fd → Cyt b6f → PC → PS I

Product: ATP only (no NADPH, no O₂)

Used when: cell needs more ATP relative to NADPH

Non-Cyclic vs Cyclic Photophosphorylation HL

AHL — C1.3.6 / C1.3.7

Non-cyclic — electrons flow in one direction (linear):

- H₂O → PS II → plastoquinone → cyt b6f → plastocyanin → PS I → Fd → NADP⁺
- Electrons are NOT recycled — they end up stored in NADPH
- Products: ATP + NADPH + O₂ (all three)

Cyclic — electrons loop back (no net products except ATP):

- PS I → ferredoxin → cyt b6f → plastocyanin → PS I (loop)
- Products: ATP ONLY
- No O₂ released, no NADPH made, no water split
- Occurs when ATP/NADPH ratio is low — supplements ATP supply

Chemiosmosis in Thylakoids HL

Chemiosmosis is the process by which cells harvest energy from a concentration gradient of protons (H⁺ ions). Protons build up on one side of a membrane, and as they flow back through a special protein (ATP synthase), their movement drives the synthesis of ATP — the same principle powers both chloroplasts and mitochondria.

Same principle as mitochondria

H⁺ (protons) accumulate in thylakoid lumen from:

1. **Photolysis:** $2\text{H}_2\text{O} \rightarrow \text{O}_2 + 4\text{H}^+ + 4\text{e}^-$ (protons released into lumen)
 2. **PQ pumping:** PQ carries H⁺ from stroma to lumen as electrons pass through
- H⁺ concentration in lumen >> stroma → steep proton gradient
 - H⁺ can ONLY move back into stroma through ATP synthase channels
 - Flow of H⁺ down the gradient powers rotation of ATP synthase → ATP

NADP Reduction HL

AHL — C1.3.7

- Ferredoxin passes 2 electrons to NADP reductase enzyme
- $\text{NADP}^+ + 2\text{e}^- + \text{H}^+$ (from stroma) → NADPH
- H⁺ comes from stroma, not from the lumen

Light-Dependent Reactions — Step by Step

1. Photon hits antenna complex of PS II. Energy passes by resonance to P680.
2. P680 absorbs energy — its electron is excited to a higher energy level.
3. Excited electron leaves P680, enters ETC via pheophytin then plastoquinone.
4. **Photolysis:** P680 is now electron-deficient (P680⁺). It oxidises water:
 $2\text{H}_2\text{O} \rightarrow 4\text{H}^+ + 4\text{e}^- + \text{O}_2$. O₂ released as waste gas.
5. Electrons pass through cytochrome b6f complex. H⁺ is actively pumped from stroma into the thylakoid lumen. This builds up the proton gradient.
6. Electrons carried by plastocyanin arrive at PS I (P700).
7. Second photon re-energises electrons at PS I. Electrons passed to ferredoxin.
8. Ferredoxin transfers electrons to NADP reductase. $\text{NADP}^+ + 2\text{e}^- + \text{H}^+ \rightarrow \text{NADPH}$.
9. H⁺ gradient across thylakoid drives ATP synthase. H⁺ flows from lumen to stroma through ATP synthase. $\text{ADP} + \text{P}_i \rightarrow \text{ATP}$ (photophosphorylation).

Chemiosmosis in the Thylakoid

MCQ Practice

Which combination of products is made by NON-CYCLIC photophosphorylation but NOT by cyclic photophosphorylation?

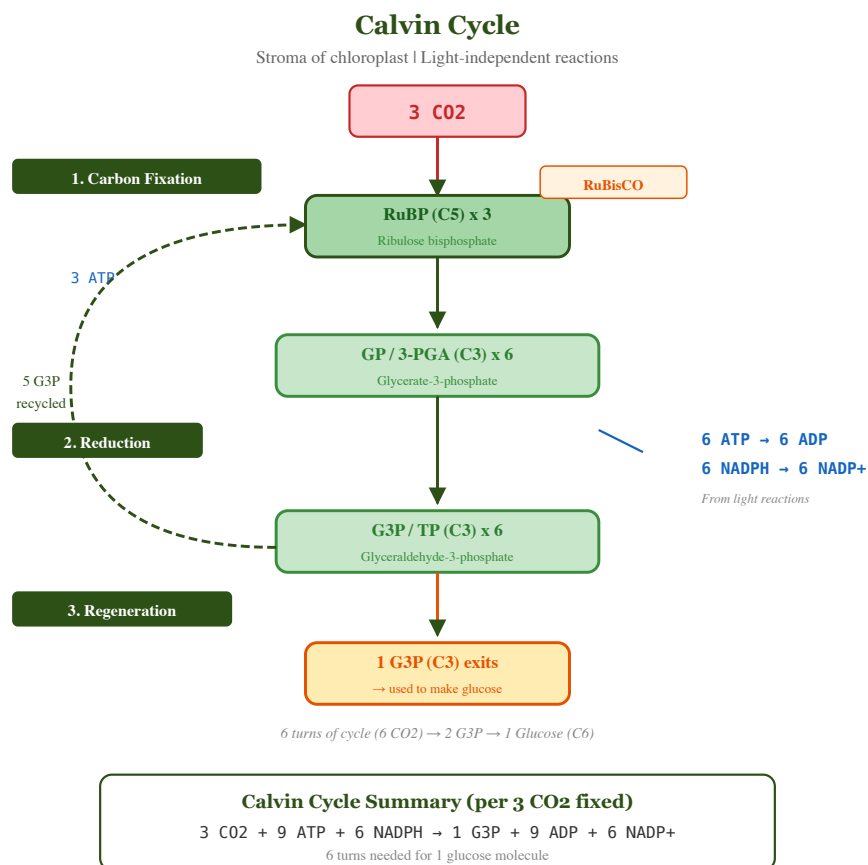
- A. ATP and CO₂
- B. NADPH and O₂ ← CORRECT**
- C. ATP and RuBP
- D. Glucose and NADPH

Why: Non-cyclic photophosphorylation produces ATP, NADPH, and O₂. Cyclic photophosphorylation produces ATP ONLY — no NADPH and no O₂ (because no photolysis occurs and electrons return to PS I). RuBP and glucose are products of the Calvin cycle, not the light reactions.

2.4 The Calvin Cycle (Light-Independent Reactions)

The Calvin cycle occurs in the **stroma**. It uses ATP and NADPH from the light reactions to **fix** CO₂ into organic molecules. The key enzyme **RuBisCO** attaches CO₂ to RuBP. The cycle regenerates its own substrate — it is truly cyclic. Three turns = one net G3P; six turns = one glucose.

The Calvin Cycle — Complete Annotated Diagram



The Calvin Cycle (Light-Independent Reactions) — occurs in the stroma

Per turn (1 CO₂ fixed):

Input: 1 CO₂ + 3 ATP + 2 NADPH → Output: $\frac{1}{3}$ G3P net

To make 1 glucose (6C) from 6 CO₂: need 6 turns of the cycle.

Total: 18 ATP + 12 NADPH consumed.

MEMORISE THIS

Key Names (must know for HL):

Abbreviation	Full Name	Carbon Atoms	Role
RuBP	Ribulose biphosphate	5C	CO ₂ acceptor
GP	3-phosphoglycerate	3C	First stable product
G3P	Glyceraldehyde-3-phosphate (triose phosphate)	3C	Organic product that exits the cycle

Calvin Cycle — Full HL Mechanism HL

AHL — C1.3.8 / C1.3.9

RuBisCO (ribulose-1,5-bisphosphate carboxylase/oxygenase) is the enzyme responsible for fixing carbon dioxide from the atmosphere into organic molecules — it is arguably the most important enzyme on Earth, and the most abundant protein in the biosphere. Without RuBisCO, photosynthesis could not convert inorganic CO_2 into the sugars that feed almost all life.

Step 1: Carbon Fixation

- RuBisCO enzyme catalyses: $\text{CO}_2 + \text{RuBP (5C)} \rightarrow$ unstable 6C intermediate
- 6C immediately splits into $2 \times \text{GP (3-phosphoglycerate, 3C)}$
- GP = the **FIRST STABLE PRODUCT** of CO_2 fixation

Step 2: Reduction — GP to G3P (triose phosphate)

- ATP phosphorylates GP $\rightarrow$ 1,3-bisphosphoglycerate (2 ATP per CO_2)
- NADPH reduces 1,3-BPG $\rightarrow$ G3P (2 NADPH per CO_2)
- G3P is the organic product that exits the cycle (1 of every 6)

Step 3: Regeneration of RuBP

- 5 of every 6 G3P molecules rearranged $\rightarrow$ ribulose-5-phosphate
- ATP phosphorylates ribulose-5-P $\rightarrow$ RuBP (3 ATP per 3 CO_2 fixed)

Interdependence of Light and Dark Reactions HL

AHL — C1.3.9

- If **light stops** $\rightarrow$ ATP and NADPH drop $\rightarrow$ **GP ACCUMULATES** (cannot be reduced)
- G3P falls, RuBP falls (cannot be regenerated)
- If **CO_2 drops** $\rightarrow$ RuBisCO slows $\rightarrow$ **RuBP accumulates**, GP falls
- Both stages are tightly coupled — neither can operate without the other

Calvin's Experiment

- Fed ^{14}C -labelled CO_2 to *Chlorella* algae, used paper chromatography
- GP (3-PGA) was the **FIRST** labelled product detected
- Proved the C3 pathway — 3-carbon first product

Calvin Cycle — Step by Step

1. CO_2 diffuses from atmosphere into stroma. RuBisCO binds CO_2 to RuBP (5C).
2. Unstable 6C intermediate immediately splits into $2 \times \text{GP (3-phosphoglycerate, 3C)}$. This is the first stable carbon fixation product.
3. ATP phosphorylates each GP molecule $\rightarrow$ 1,3-bisphosphoglycerate. (2 ATP used per CO_2)

4. NADPH reduces 1,3-BPG $\rightarrow$ G3P (triose phosphate). (2 NADPH used per CO_2)
5. 1 out of every 6 G3P molecules exits the cycle to make glucose, fatty acids, or amino acids.
6. The remaining 5 G3P molecules enter the RuBP regeneration pathway.
7. ATP is used to phosphorylate ribulose-5-phosphate $\rightarrow$ RuBP. (3 ATP per 3 CO_2 fixed)
8. RuBP is ready to accept another CO_2 . The cycle repeats.

MCQ Practice

If light intensity suddenly drops to zero during active photosynthesis, what immediate change is observed in the Calvin cycle?

- A. RuBP levels increase because carbon fixation continues
- B. GP levels decrease because it can no longer be made
- C. GP accumulates because it cannot be reduced to G3P without NADPH $\leftarrow$ CORRECT**
- D. CO_2 levels inside the chloroplast increase

Why: With no light: ATP and NADPH production stops. RuBisCO can still make GP (as long as RuBP and CO_2 are present), but GP CANNOT be reduced to G3P because NADPH is needed for that step. So GP builds up. G3P falls. RuBP is gradually used up and not regenerated. This interdependence question is extremely common in HL exams.

MCQ Practice

Which molecule is the DIRECT product of carbon fixation by RuBisCO?

- A. G3P (triose phosphate)
- B. Glucose
- C. RuBP
- D. GP (3-phosphoglycerate) $\leftarrow$ CORRECT**

Why: RuBisCO catalyses $\text{CO}_2 + \text{RuBP} \rightarrow \text{unstable } 6\text{C} \rightarrow 2 \times \text{GP}$ (3-phosphoglycerate). GP is the FIRST stable product of carbon fixation. G3P is made AFTER GP is reduced using ATP and NADPH. Glucose is made after multiple turns of the cycle.

►Watch: Photosynthesis — Light Reactions and Calvin Cycle

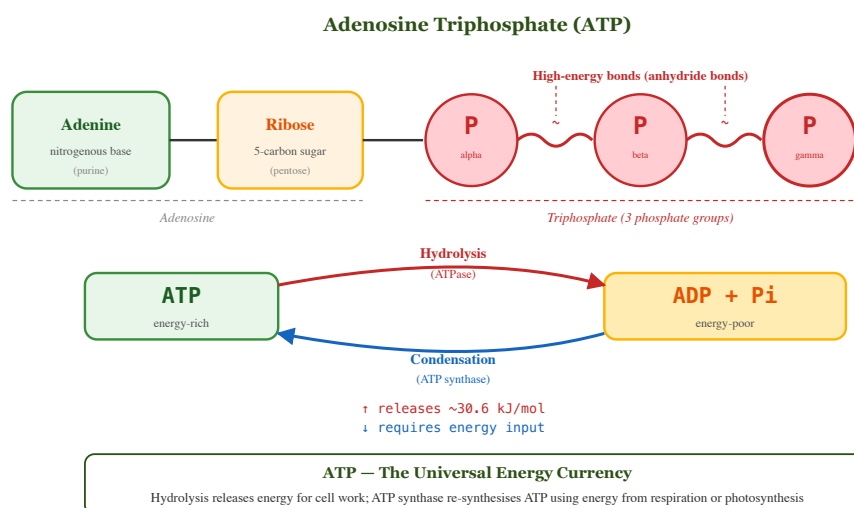
VIDEO

Section 3: Cellular Respiration

Cellular respiration releases energy from organic molecules and stores it as ATP. Four stages: **Glycolysis** (cytoplasm) → **Link Reaction** (matrix) → **Krebs Cycle** (matrix) → **Electron Transport Chain and Chemiosmosis** (inner membrane). Understanding each stage's location, inputs, outputs, and mechanism is essential for HL.

3.1 ATP and NAD — Energy Carriers

ATP Structure and the Energy Cycle

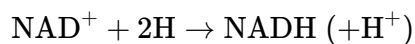


ATP Structure — adenine + ribose + 3 phosphate groups, with the ATP-ADP cycle

- ATP drives: active transport, movement, anabolism (synthesis reactions)
- ATP is NOT stored — it is rapidly recycled (~40 kg ATP cycled per day in humans)

NAD (Nicotinamide Adenine Dinucleotide)

- **Oxidised form:** NAD^+ (empty — can accept electrons)
- **Reduced form:** NADH (loaded — carrying electrons + H)



- Substrate is **oxidised** (loses H)
- NAD^+ is **reduced** (gains H)

FADH_2 : similar to NADH but carries slightly less energy. Used at one specific step in the Krebs cycle (succinate → fumarate).

MEMORISE THIS

OIL RIG

- **Oxidation = Is Loss** of electrons/hydrogen (substrate → product loses H)

- **Reduction = Is Gain of electrons/hydrogen** ($\text{NAD}^+ \rightarrow \text{NADH}$ gains H)

Role of NAD as Hydrogen Carrier HL

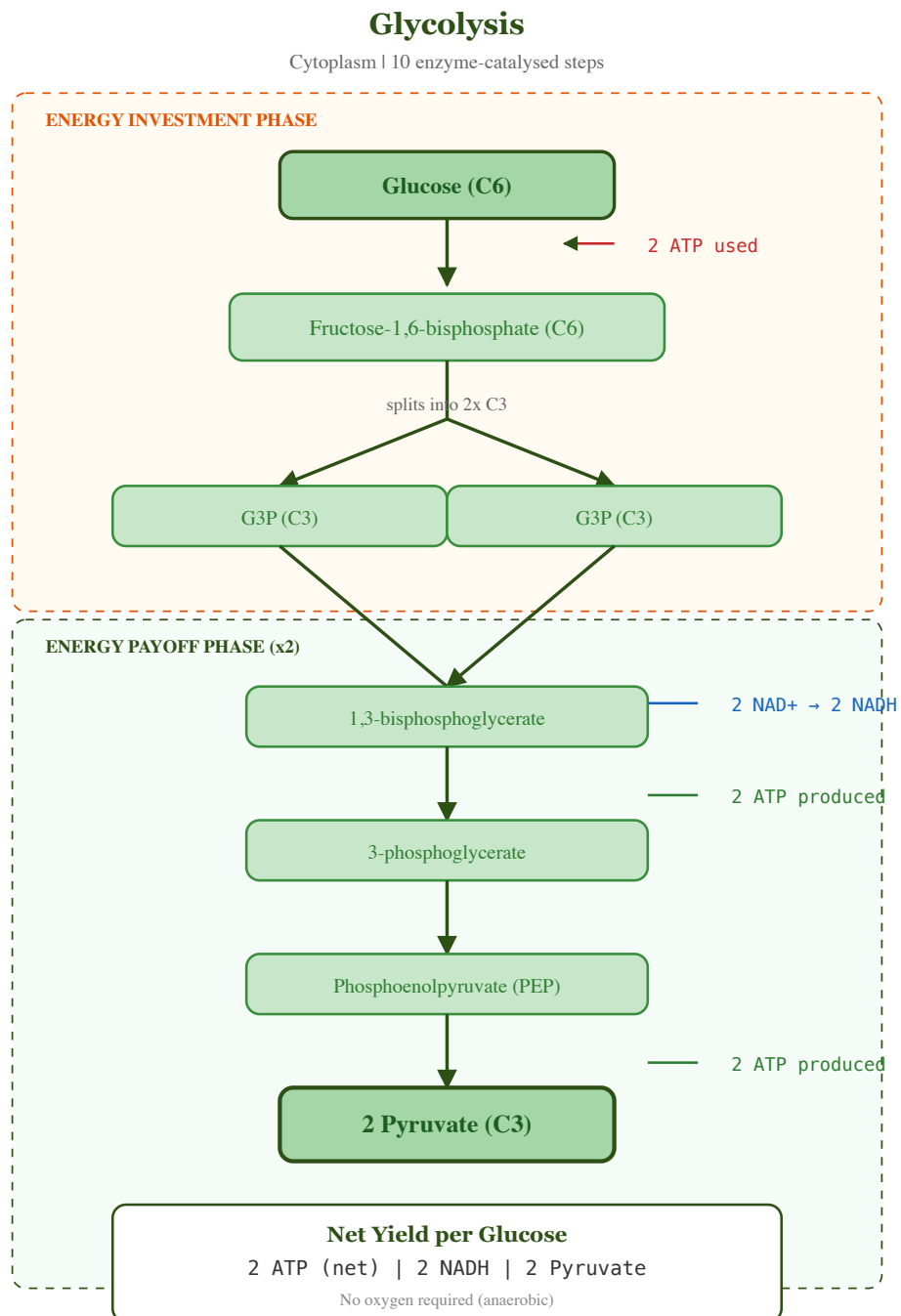
AHL — C1.2.7

- NAD^+ acts as the hydrogen (electron + proton) ACCEPTOR during substrate oxidation
- Each NADH carries 2 electrons + 1 H^+ to the electron transport chain
- At the ETC, NADH is OXIDISED $\rightarrow$ NAD^+ is regenerated
- NAD^+ must be regenerated continuously — without it, glycolysis and Krebs stop
- **In aerobic conditions:** NAD^+ regenerated at the ETC (O_2 accepts electrons at end)
- **In anaerobic conditions:** NAD^+ regenerated by fermentation (pyruvate or acetaldehyde accepts electrons)
- FADH_2 also donates electrons to the ETC but enters at a later complex $\rightarrow$ yields slightly less ATP than NADH (~2 vs ~3 ATP per molecule)

3.2 Glycolysis

Location: CYTOPLASM (cytosol). Glycolysis is the ONLY stage shared by aerobic and anaerobic respiration. One glucose (6C) $\rightarrow$ two pyruvate (3C), with a net yield of 2 ATP and 2 NADH. No oxygen required.

Glycolysis — Step-by-Step Flow



Glycolysis: Glucose to Pyruvate (occurs in the cytoplasm)

Per glucose	
ATP used	2 (phosphorylation)
ATP made	4 (substrate-level phosphorylation)
Net ATP	+2
NADH produced	2
Pyruvate made	2 x 3C

Glycolysis — HL Mechanism HL

AHL — C1.2.8

Stage 1 — Phosphorylation:

- 2 ATP hydrolysed → glucose receives 2 phosphate groups
- Forms fructose-1,6-bisphosphate (6C, 2 phosphates)
- **Why:** Adding phosphates destabilises the molecule, making it easy to split AND traps glucose inside the cell (phosphorylated glucose cannot cross membranes)

Stage 2 — Lysis:

- Fructose-1,6-bisphosphate → 2 × triose phosphate (G3P, 3C each)
- Each G3P retains 1 phosphate group from the phosphorylation step

Stage 3 — Oxidation:

- Each G3P oxidised — removes 2H (electrons + protons)
- NAD^+ accepts the hydrogen → NADH formed (2 total)
- A second inorganic phosphate (P_i) is added to each G3P
- Molecule now has 2 phosphate groups and is highly energised

Stage 4 — ATP Formation (substrate-level phosphorylation):

- Each of the 2 phosphate groups is transferred directly to ADP
- 4 ATP produced in total (2 phosphates transferred per pyruvate × 2 G3P)
- Net: 4 made - 2 used = **2 ATP net**

IB TIP

Note: Specific intermediate names are NOT required by the IB 2025 syllabus, but you MUST know the 4 stages and their inputs/outputs.

MCQ Practice

A cell is fed glucose labelled with ^{14}C at every carbon atom. After glycolysis only (no further reactions), in which molecule(s) would ALL the ^{14}C be found?

- A. CO_2 only
- B. ATP and NADH
- C. Pyruvate ← CORRECT**
- D. CO_2 and pyruvate equally

Why: Glycolysis converts glucose to pyruvate — NO CO_2 is released in glycolysis. All 6 carbons end up in the 2 pyruvate molecules (3C each). CO_2 is released in the LINK REACTION (1 CO_2 per pyruvate) and KREBS CYCLE. ATP and NADH carry no carbon atoms from glucose.

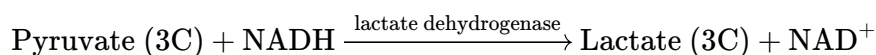
3.3 Anaerobic Respiration

When oxygen runs out — during intense exercise or in environments without air — cells can't use the ETC to regenerate the NAD^+ that glycolysis depends on.

Fermentation is the emergency solution: it uses pyruvate (or a derivative) to accept the electrons instead, keeping glycolysis running and ATP production alive, though at a much lower yield.

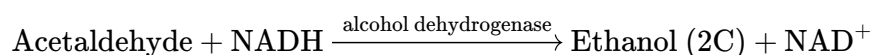
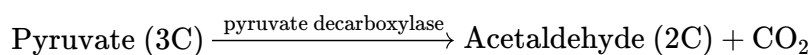
When O_2 is absent, cells must **regenerate** NAD^+ without using the ETC. The **ONLY** purpose of fermentation is to recycle NAD^+ so glycolysis can continue. Two pathways exist — one in animals, one in yeast.

Lactate Fermentation (Animals / Humans)



- Pyruvate is REDUCED to lactate
- NADH is OXIDISED back to NAD^+ — **this is the WHOLE POINT**
- NAD^+ recycled → glycolysis can continue producing ATP
- Lactate accumulates in muscle → transported to liver (Cori cycle)
- When O_2 returns: lactate → pyruvate → aerobic pathway (oxygen debt)
- **Net ATP: 2 per glucose (glycolysis only)**
- **REVERSIBLE** reaction

Ethanol Fermentation (Yeast)



- CO_2 is released (used in baking = bread rises; fermentation = carbonation)
- Ethanol accumulates — toxic to yeast at concentrations $> \sim 15\%$
- **IRREVERSIBLE** — yeast cannot convert ethanol back to pyruvate
- **Net ATP: 2 per glucose (glycolysis only)**

Comparison

	Both pathways	Animals	Yeast
Purpose	Regenerate NAD^+	Lactate (3C)	Ethanol (2C) + CO_2
ATP yield	2 only	2 only	2 only
Location	Cytoplasm	Cytoplasm	Cytoplasm
Reversibility	—	Reversible	Irreversible

Anaerobic Respiration — HL Points HL

AHL — C1.2.9 / C1.2.10 / C1.2.17

⚠ EXAM ALERT

Key Concept: The purpose of fermentation is NOT to produce energy — it is to regenerate NAD^+ so glycolysis can KEEP producing ATP. Without NAD^+ , glycolysis stops at the oxidation step and no ATP is made.

Lipids vs Carbohydrates as Respiratory Substrates HL

AHL — C1.2.17

- Lipids yield ~2x more energy per gram than carbohydrates
- **Why:** Lipids are more reduced — they contain more C-H bonds per carbon (more hydrogen to be oxidised → more NADH → more ATP from ETC)
- Lipids contain very little oxygen already bound → more oxidation can occur
- Glycerol component → enters glycolysis
- Fatty acids → beta-oxidation in mitochondrial matrix → Acetyl-CoA → Krebs

⚠ EXAM ALERT

Important: Glycolysis and anaerobic respiration can ONLY use carbohydrates. Lipids BYPASS glycolysis entirely — they enter as Acetyl-CoA at the link reaction level.

MCQ Practice

Why must NAD^+ be regenerated during anaerobic respiration?

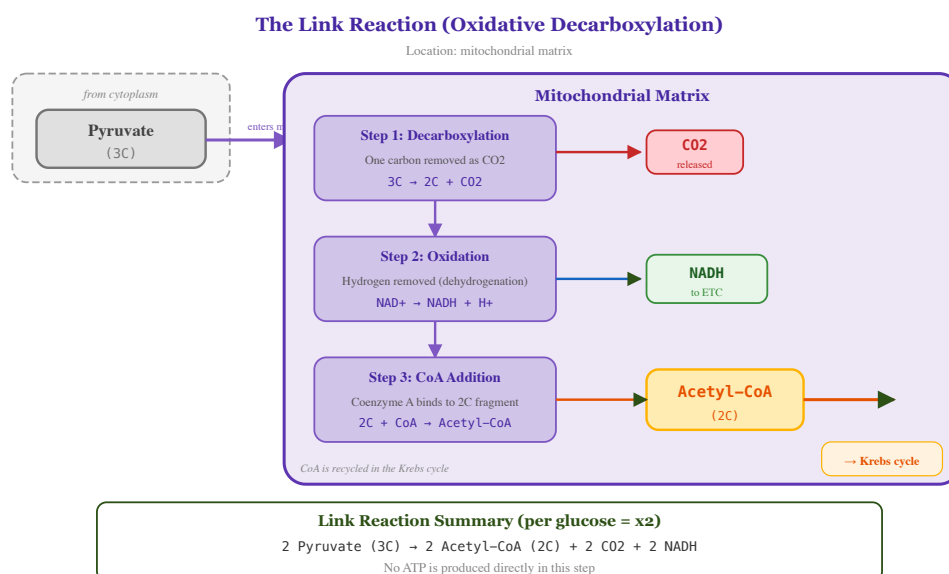
- A. NAD^+ is needed to drive the electron transport chain
- B. NAD^+ is required for oxidation of glucose in the Krebs cycle
- C. **Without NAD^+ , glycolysis cannot oxidise triose phosphate, so ATP production stops ← CORRECT**
- D. NAD^+ is needed to split water during photolysis

Why: Glycolysis REQUIRES NAD^+ in the oxidation step to accept hydrogen from triose phosphate. Without NAD^+ , this step stalls, glycolysis cannot proceed, and no ATP is produced. Fermentation regenerates NAD^+ by using pyruvate (or acetaldehyde) as an electron acceptor instead. The ETC is not available in anaerobic conditions.

3.4 The Link Reaction

Location: mitochondrial matrix. Pyruvate (3C) from glycolysis is converted to Acetyl-CoA (2C), releasing CO_2 . This connects glycolysis to the Krebs cycle. Two link reactions occur per glucose (two pyruvate molecules).

Link Reaction — Full Diagram



Link Reaction — pyruvate to Acetyl-CoA in the mitochondrial matrix

	Per pyruvate	Per glucose
CO ₂ released	1	2
NADH produced	1	2
Acetyl-CoA formed	1	2

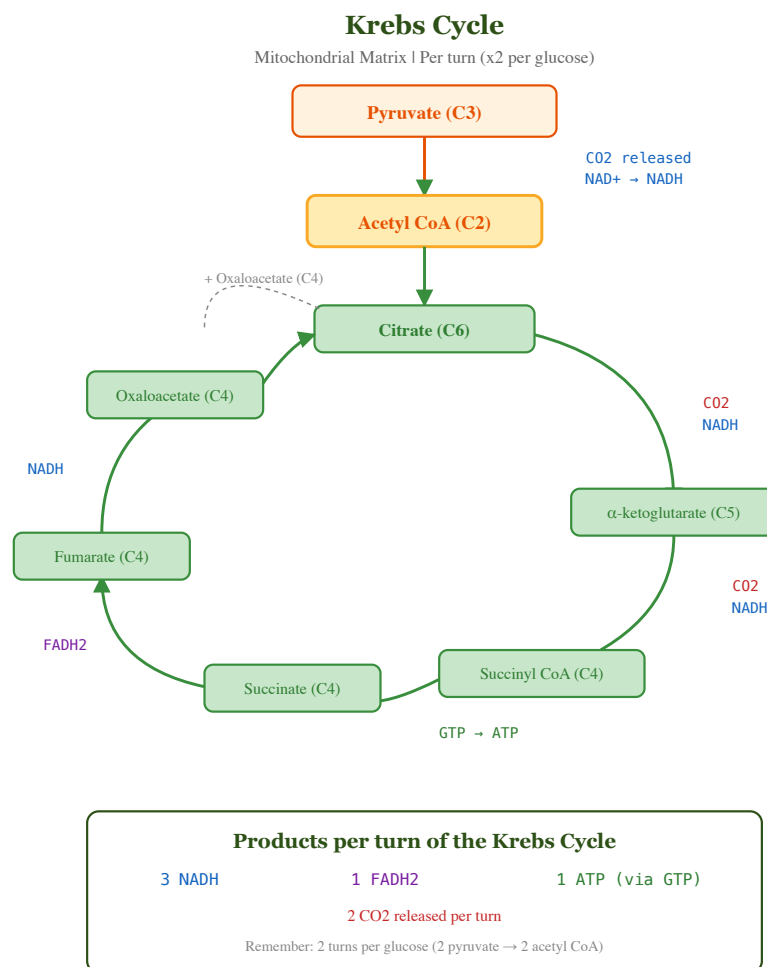
- CoA = Coenzyme A (acts as a carrier/handle for the acetyl group)
- CoA is released when Acetyl-CoA enters Krebs, and is recycled

3.5 The Krebs Cycle

The Krebs cycle is a series of reactions that completely strips the remaining energy from the products of glycolysis — not by making much ATP directly, but by loading electrons onto carrier molecules (NADH and FADH₂) that will deliver those electrons to the ETC where most of the ATP is made. Think of the Krebs cycle as the electron-loading stage.

Location: mitochondrial matrix. The Krebs cycle fully oxidises Acetyl-CoA, releasing CO₂ and producing large amounts of NADH and FADH₂. These electron carriers deliver energy to the ETC. The 4C oxaloacetate starting molecule is regenerated each turn — making it truly cyclic.

The Krebs Cycle — Complete Annotated Diagram



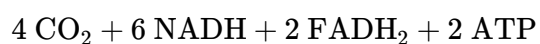
The Krebs Cycle (Citric Acid Cycle) — occurs in the mitochondrial matrix

Interactive Step-by-step animated walkthrough of the Krebs Cycle

Per turn (per Acetyl-CoA = per 1/2 glucose):

Product	Amount
CO ₂ released	2
NADH produced	3
FADH ₂ produced	1
ATP (substrate-level phosphorylation)	1

Per glucose (2 turns):



MEMORISE THIS

Must-know intermediates: Citrate (6C) and Oxaloacetate (4C)

Krebs Cycle — HL Detail HL

AHL — C1.2.12

Condensation: Acetyl-CoA (2C) + Oxaloacetate (4C) → Citrate (6C) + CoA released.
CoA is recycled to pick up another acetyl group from the link reaction.

1st Decarboxylation: Isocitrate → alpha-ketoglutarate. CO_2 released + NAD^+ reduced to NADH.

2nd Decarboxylation: alpha-ketoglutarate → Succinyl-CoA. CO_2 released + NAD^+ reduced to NADH.

Substrate-level Phosphorylation: Succinyl-CoA → Succinate. 1 ATP produced directly (not via ETC). CoA released.

FAD Reduction: Succinate → Fumarate. FAD reduced to FADH_2 (not NAD^+).

- **Why FAD here?** This oxidation step has insufficient energy to reduce NAD^+ . Succinate dehydrogenase enzyme is embedded in the inner mitochondrial membrane.

Malate Oxidation: Malate → Oxaloacetate. NAD^+ reduced to NADH. Oxaloacetate regenerated → cycle continues.

Products summary (per turn): 3 NADH + 1 FADH_2 + 1 ATP + 2 CO_2 (+ regenerated oxaloacetate)

Krebs Cycle — Step by Step

1. Acetyl-CoA (2C) enters the matrix. CoA is released and recycled to the link reaction.
2. Condensation: acetyl group (2C) combines with oxaloacetate (4C) → citrate (6C).
3. Citrate rearranged → isocitrate (same formula, different structure).
4. 1st decarboxylation: isocitrate → alpha-ketoglutarate (5C) + CO_2 . $\text{NAD}^+ \rightarrow \text{NADH}$.
5. 2nd decarboxylation: alpha-ketoglutarate → succinyl-CoA (4C) + CO_2 . $\text{NAD}^+ \rightarrow \text{NADH}$.
6. Substrate-level phosphorylation: succinyl-CoA → succinate + 1 ATP. CoA released.
7. Oxidation: succinate → fumarate. $\text{FAD} \rightarrow \text{FADH}_2$.
8. Hydration: fumarate + $\text{H}_2\text{O} \rightarrow$ malate.
9. Oxidation: malate → oxaloacetate. $\text{NAD}^+ \rightarrow \text{NADH}$. Oxaloacetate ready for next turn.

MCQ Practice

How many molecules of CO_2 are produced per turn of the Krebs cycle (per acetyl-CoA)?

- A. 1
- B. 2 ← CORRECT**
- C. 3
- D. 4

Why: Two CO_2 molecules are released per turn of the Krebs cycle — one at each of the two decarboxylation steps (isocitrate $\rightarrow$ α -KG and α -KG $\rightarrow$ succinyl-CoA). Per glucose (2 turns): 4 CO_2 from Krebs + 2 CO_2 from the link reaction = 6 CO_2 total from Krebs + link (matching the 6 CO_2 in the overall equation).

MCQ Practice

Which is the only Krebs cycle step that produces FADH_2 rather than NADH ?

- A. Isocitrate $\rightarrow$ α -ketoglutarate
- B. α -ketoglutarate $\rightarrow$ succinyl-CoA
- C. Succinate $\rightarrow$ fumarate ← CORRECT**
- D. Malate $\rightarrow$ oxaloacetate

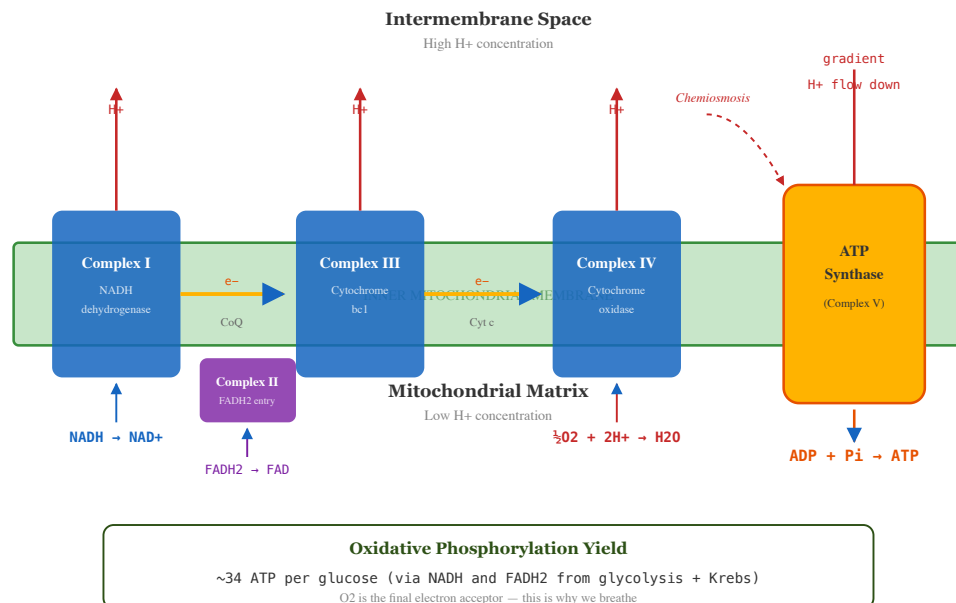
Why: FAD (rather than NAD^+) is the hydrogen acceptor at the succinate $\rightarrow$ fumarate step. This is because the oxidation of succinate releases insufficient energy to reduce NAD^+ . Succinate dehydrogenase is the enzyme, and it is embedded in the inner mitochondrial membrane. All other oxidative steps use NAD^+ .

3.6 Electron Transport Chain and Chemiosmosis

The electron transport chain (ETC) is where the majority of ATP is produced during aerobic respiration. Electrons carried by NADH and FADH_2 pass through a series of proteins in the inner mitochondrial membrane, releasing energy that pumps protons across the membrane. The resulting proton gradient then drives ATP synthase — a process called oxidative phosphorylation because it uses oxygen as the final electron acceptor to keep the whole chain running.

Location: INNER MITOCHONDRIAL MEMBRANE. NADH and FADH_2 from glycolysis, the link reaction, and the Krebs cycle deliver electrons to protein complexes embedded in the inner membrane. As electrons flow down the chain, H^+ is pumped into the intermembrane space. The proton gradient drives ATP synthesis through chemiosmosis. O_2 is the FINAL electron acceptor.

Electron Transport Chain and Chemiosmosis — Diagram



Electron Transport Chain & Oxidative Phosphorylation — inner mitochondrial membrane

Interactive Step-by-step animated walkthrough of the ETC

- $\text{NADH} \rightarrow \sim 3 \text{ ATP}$
- $\text{FADH}_2 \rightarrow \sim 2 \text{ ATP}$ (enters at ubiquinone, skips Complex I)
- O_2 is ESSENTIAL — without it, ETC stops, H^+ not pumped, no ATP
- Water is produced at Complex IV (matrix side of inner membrane)
- ATP yield from ETC per glucose: ~34 ATP

ETC and Chemiosmosis — HL Mechanisms HL

AHL — C1.2.13 to C1.2.16

Energy Transfer to ETC (AHL C1.2.13):

- NADH delivers electrons to Complex I (NADH dehydrogenase)
- FADH_2 delivers electrons to Complex II (succinate dehydrogenase) via ubiquinone
- As electrons pass through each complex, energy released pumps H^+ into IMS
- FADH_2 yields LESS ATP than NADH because it bypasses Complex I (less H^+ pumped)

Proton Gradient Generation (AHL C1.2.14):

- Complexes I, III, and IV all pump H^+ from matrix into intermembrane space (IMS)
- IMS has small volume $\rightarrow \text{H}^+$ accumulates quickly $\rightarrow$ steep concentration gradient
- Electrochemical gradient = proton motive force (concentration + charge difference)

Chemiosmosis and ATP Synthesis (AHL C1.2.15):

- H^+ can ONLY re-enter the matrix through ATP synthase (Complex V)
- Flow of H^+ down the gradient causes mechanical rotation of ATP synthase
- Rotation drives conformational changes in ATP synthase $\rightarrow ADP + P_i \rightarrow ATP$
- $\sim 3 H^+$ needed per ATP molecule (approximate, accepted by IB)

Role of O_2 (AHL C1.2.16):

- O_2 is the TERMINAL (final) electron acceptor at Complex IV
- $O_2 + 4e^- + 4H^+ \rightarrow 2H_2O$ (water produced in the matrix)
- WITHOUT O_2 : electrons cannot leave Complex IV $\rightarrow$ ETC completely blocks
- Blocked ETC $\rightarrow H^+$ not pumped $\rightarrow$ no gradient $\rightarrow$ no ATP synthesis
- NADH/FADH₂ cannot be oxidised $\rightarrow NAD^+$ runs out $\rightarrow$ Krebs and link reaction stop
- ONLY glycolysis (with fermentation for NAD^+ regeneration) continues without O_2

ETC and Chemiosmosis — Step by Step

1. NADH (from glycolysis, link reaction, Krebs) passes electrons to Complex I. FADH₂ passes electrons to ubiquinone (bypassing Complex I).
2. Electrons flow from Complex I $\rightarrow$ ubiquinone $\rightarrow$ Complex III $\rightarrow$ cytochrome c $\rightarrow$ Complex IV.
3. At each complex (I, III, IV), energy from electron flow pumps H^+ from matrix into the intermembrane space.
4. H^+ accumulates in the intermembrane space — builds up a steep concentration gradient (proton motive force).
5. H^+ can ONLY flow back into the matrix through ATP synthase channels.
6. H^+ flowing through ATP synthase causes it to rotate — this mechanical energy drives synthesis of ATP from $ADP + P_i$ (oxidative phosphorylation).
7. At Complex IV: electrons are transferred to O_2 . $O_2 + \text{electrons} + H^+ \rightarrow H_2O$. Water is the final product of the ETC.
8. NAD^+ and FAD are regenerated and return to the Krebs cycle and link reaction to pick up more electrons.

MCQ Practice

Why does aerobic respiration stop if oxygen is removed, even though glycolysis does not require oxygen?

A. Oxygen is needed to activate RuBisCO in the matrix

B. Without oxygen the ETC stops, NADH cannot be oxidised, NAD^+ runs out, and the Krebs cycle stops ← CORRECT

C. Oxygen is required for the condensation reaction in the Krebs cycle

D. Without oxygen, pyruvate cannot enter the mitochondrial matrix

Why: Oxygen is the terminal electron acceptor at the end of the ETC. Without it, electrons cannot leave Complex IV, the ETC backs up, NADH cannot be oxidised to NAD^+ , and NAD^+ runs out. Without NAD^+ , the Krebs cycle and link reaction cannot proceed. Only glycolysis continues, using fermentation to regenerate NAD^+ . This is a classic chain-of-consequence MCQ.

MCQ Practice

A cell is treated with a drug that blocks ATP synthase. Which prediction is correct?

- A. The ETC stops immediately because ATP synthase is needed to power it
- B. The proton gradient across the inner membrane breaks down
- C. The proton gradient increases because H^+ is still pumped but cannot return ← CORRECT**
- D. NADH production increases because more substrate is oxidised

Why: If ATP synthase is blocked, H^+ can no longer flow back into the matrix. However, the ETC continues pumping H^+ into the IMS (as long as O_2 and NADH are available). The gradient therefore INCREASES but no ATP is made. Eventually the gradient becomes so steep that ETC pumping slows (back-pressure), reducing NADH oxidation too.

►Watch: Cellular Respiration — Glycolysis, Krebs Cycle, and ETC

VIDEO

Section 4: ATP Yield — The Full Accounting

Understanding the ATP yield at each stage and why the ETC produces so much more ATP than glycolysis is crucial for both MCQ and extended-response questions.

Complete ATP Yield Table — Per Glucose

Stage	Location	Inputs	Outputs	ATP per glucose
Glycolysis	Cytoplasm	Glucose	2 Pyruvate, 2 NADH	2 net
Link Reaction	Mito. matrix	2 Pyruvate	2 Acetyl-CoA, 2 CO_2 , 2 NADH	0
Krebs Cycle	Mito. matrix	2 Acetyl-CoA	4 CO_2 , 6 NADH, 2 FADH_2	2
ETC + ATP synthase	Inner mito. membrane	10 NADH, 2 FADH_2	H_2O	~34
TOTAL	Both	Glucose + O_2	$\text{CO}_2 + \text{H}_2\text{O}$	~38

Why Does the ETC Produce ~34 ATP While Glycolysis Makes Only 2?

Glycolysis and Krebs use **substrate-level phosphorylation** — ATP is made DIRECTLY when a phosphate group is transferred to ADP. This only happens at a few specific steps → low yield.

The ETC uses **oxidative phosphorylation** — a completely different mechanism:

- 10 NADH + 2 FADH₂ carry electrons to the ETC
- As electrons pass through protein complexes, their energy pumps H⁺
- A large proton gradient drives ATP synthase to make ATP
- ~2.5 ATP per NADH and ~1.5 ATP per FADH₂ (approximately 3 and 2 for IB)
- 10 NADH x 3 = 30 ATP
- 2 FADH₂ x 2 = 4 ATP
- **Total from ETC: ~34 ATP**

IB TIP

Note: Actual yield is slightly lower than 38 due to: some H⁺ leaking across the inner membrane, ATP synthase not being 100% efficient, and the energy cost of transporting pyruvate and ADP into the matrix. IB accepts 36-38 ATP as the aerobic yield per glucose.

MCQ Practice

Which statement explains why FADH₂ yields fewer ATP molecules than NADH during oxidative phosphorylation?

- A. FADH₂ carries fewer electrons than NADH
- B. FADH₂ cannot enter the mitochondrial matrix
- C. FADH₂ donates electrons at a later point in the ETC, bypassing Complex I, so fewer H⁺ are pumped ← CORRECT**
- D. FADH₂ is oxidised in the cytoplasm, not the mitochondria

Why: FADH₂ delivers electrons directly to ubiquinone (between Complexes I and III), bypassing Complex I entirely. Since Complex I pumps H⁺ as electrons pass through it, skipping it means fewer H⁺ are pumped into the IMS, creating a smaller contribution to the proton gradient, and therefore fewer ATP molecules are synthesised per FADH₂.

Section 5: MCQ Strategy and Common Traps

IB Biology Paper 1 MCQs test whether you know **exact locations**, **exact sequences**, **exact products**, and can **follow chains of consequence**. The most effective strategy: read the question, **predict your answer before looking at options**, then check. This prevents attractive wrong answers from misleading you.

The Most Common MCQ Traps — Memorise These

 EXAM ALERT	
Common Wrong Answer / Misconception	
Correct Understanding	
O ₂ comes from CO ₂ in photosynthesis	O ₂ comes from PHOTOLYSIS of water (H ₂ O → O ₂). CO ₂ is fixed into glucose — never releases O ₂ .
Krebs cycle is on the inner membrane	Krebs cycle is in the MATRIX. The ETC and ATP synthase are on the INNER MEMBRANE.
Glycolysis is in the mitochondria	Glycolysis is in the CYTOPLASM. It occurs in BOTH aerobic and anaerobic conditions.
PS II comes after PS I in electron flow	PS II comes FIRST (P680, splits water). PS I comes second (P700, reduces NADP ⁺). Numbers are confusing.
Fermentation produces ATP	Fermentation's purpose is to regenerate NAD ⁺ . It produces NO additional ATP beyond glycolysis.
FADH ₂ and NADH yield equal ATP	NADH yields ~3 ATP; FADH ₂ yields ~2 ATP. FADH ₂ skips Complex I so fewer H ⁺ are pumped.
Calvin cycle needs light	Calvin cycle uses ATP and NADPH from light reactions but does NOT directly require light itself. It stops when LIGHT STOPS only because ATP/NADPH run out.
Link reaction produces ATP	Link reaction produces ONLY CO ₂ , NADH, and Acetyl-CoA. NO ATP is produced at this stage.
CO ₂ is released in glycolysis	No CO ₂ in glycolysis. CO ₂ is released in the LINK REACTION (1 per pyruvate) and KREBS CYCLE (2 per turn).
Non-cyclic and cyclic produce the same products	Non-cyclic → ATP + NADPH + O ₂ . Cyclic → ATP ONLY. This is a very frequent MCQ distinction.

Five MCQ Strategy Rules for IB Biology

- 1. Predict before reading options:** Cover the answers. Decide what you think the answer is. Then check. This avoids being misled by plausible-sounding distractors.
- 2. Location questions — go to your mental map:** Ask: is this a membrane process (ETC, light reactions) or a fluid/matrix process (Krebs, Calvin, glycolysis)? This eliminates 2-3 wrong options instantly.

3. **“Cannot proceed because...” questions — trace the chain:** Work step by step: what stops first? What runs out next? For example: no $O_2 \rightarrow$ ETC stops $\rightarrow$ NADH not oxidised $\rightarrow$ NAD^+ runs out $\rightarrow$ Krebs stops.
4. **Product counting questions — add up from your diagrams:** Know exact yields: Glycolysis = 2 ATP; Link = 0 ATP, 2 NADH; Krebs = 2 ATP, 6 NADH, 2 $FADH_2$, 4 CO_2 ; ETC = ~ 34 ATP.
5. **“Increases/decreases” questions — think about the feedback:** e.g. “light stops $\rightarrow$ what happens to GP?” $\rightarrow$ ATP and NADPH drop $\rightarrow$ GP CANNOT be reduced $\rightarrow$ GP ACCUMULATES. Always follow the logic, not the memory.

MCQ Practice

During aerobic respiration, where are the protons (H^+) that flow through ATP synthase coming from?

- A. From the hydrolysis of ATP in the matrix
- B. From water produced at Complex IV
- C. From the oxidation of NADH and $FADH_2$, pumped into the intermembrane space by the ETC $\leftarrow$ CORRECT**
- D. From the breakdown of glucose during glycolysis

Why: When NADH and $FADH_2$ deliver electrons to the ETC, the energy released pumps H^+ from the matrix into the intermembrane space (via Complexes I, III, and IV). These accumulated H^+ then flow back through ATP synthase into the matrix, driving ATP synthesis. Water is produced at Complex IV (where O_2 accepts electrons), not as a source of H^+ for ATP synthase.

MCQ Practice

A plant is moved from red light to green light only. What happens to the rate of photosynthesis?

- A. It increases because plants can use all visible light equally
- B. It stays the same because the Calvin cycle does not require light
- C. It decreases significantly because chlorophyll absorbs very little green light $\leftarrow$ CORRECT**
- D. It stops completely because green light has too little energy to excite electrons

Why: Chlorophyll a and b absorb mainly blue and red light — they REFLECT green light (which is why leaves look green). Very little green light is absorbed, so photosynthesis rate drops sharply. It does not stop completely because carotenoids absorb some green-adjacent wavelengths. The action spectrum confirms photosynthesis is lowest in the green region.

MCQ Practice

Which statement about the relationship between photosynthesis and aerobic respiration is correct?

- A. Both processes occur only in plant cells
- B. The ATP produced in photosynthesis is directly used in respiration
- C. Oxygen produced in photosynthesis is the same oxygen consumed in aerobic respiration ← CORRECT**
- D. Both processes produce carbon dioxide as a final waste product

Why: O₂ produced by photolysis in the light reactions is the same O₂ that acts as the terminal electron acceptor in the mitochondrial ETC. This links the two processes: the oxygen cycle. ATP from photosynthesis is NOT directly transferred to respiration — it is used to make glucose in the Calvin cycle, and glucose is then respired. Respiration occurs in ALL living cells, not just plants. Respiration releases CO₂; photosynthesis CONSUMES CO₂.

Section 6: HL Content — Complete Checklist HL

This checklist covers every AHL (Additional Higher Level) point for photosynthesis and respiration in the 2025 IB Biology syllabus. If you are HL, every item on this list is assessable.

HL Photosynthesis — What You Must Know

AHL Topic	Key Points to Know
Chloroplast adaptations (B2.2.5)	Large thylakoid membrane surface area; small lumen volume builds H^+ gradient fast; stroma compartmentalises Calvin cycle enzymes
Photosystem structure (C1.3.5)	Antenna complex = array of accessory pigments; reaction centres P680 (PS II) and P700 (PS I); $P680^+$ is strongest biological oxidising agent
Non-cyclic vs cyclic photophosphorylation (C1.3.6)	Non-cyclic: PS I + PS II, products ATP + NADPH + O_2 . Cyclic: PS I only, product ATP only. Electron flow directions.
NADP reduction (C1.3.7)	Ferredoxin $\rightarrow$ NADP reductase $\rightarrow NADP^+ + 2e^- + H^+$ (stroma) $\rightarrow$ NADPH
Chemiosmosis in thylakoid (C1.3.12)	H^+ pumped into lumen by PQ + cyt b6f; small lumen volume $\rightarrow$ steep gradient; H^+ returns via ATP synthase $\rightarrow$ ATP
Calvin cycle mechanism (C1.3.8)	3 stages: carbon fixation (RuBisCO, $CO_2 + RuBP \rightarrow GP$), reduction (ATP + NADPH, $GP \rightarrow G3P$), regeneration (ATP, $G3P \rightarrow RuBP$). Per glucose: 18 ATP + 12 NADPH
Interdependence of stages (C1.3.9)	Light stops $\rightarrow$ ATP/NADPH fall $\rightarrow$ GP accumulates $\rightarrow$ G3P falls $\rightarrow$ RuBP falls. CO_2 falls $\rightarrow$ RuBP accumulates, GP falls.
Calvin's experiment	$^{14}CO_2$ + paper chromatography $\rightarrow$ GP was first stable product; proved C3 pathway

HL Respiration — What You Must Know

AHL Topic	Key Points to Know
NAD as hydrogen carrier (C1.2.7)	NAD^+ accepts H during oxidation of substrate $\rightarrow \text{NADH}$; NADH delivers electrons to ETC; NAD^+ regenerated by ETC (aerobic) or fermentation (anaerobic)
Glycolysis stages (C1.2.8)	4 stages: phosphorylation (-2 ATP), lysis, oxidation (2 NADH), ATP formation (+4 ATP). Net: 2 ATP + 2 NADH. Cytoplasm. Both aerobic and anaerobic.
Lactate fermentation (C1.2.9)	Pyruvate $\rightarrow$ lactate + NAD^+ . Purpose: regenerate NAD^+ . Reversible. No extra ATP.
Yeast fermentation (C1.2.10)	Pyruvate $\rightarrow$ acetaldehyde + CO_2 , then acetaldehyde + $\text{NADH} \rightarrow$ ethanol + NAD^+ . Irreversible. Used in baking/brewing.
Link reaction (C1.2.11)	Pyruvate $\rightarrow$ Acetyl-CoA. Decarboxylation + oxidation. Per pyruvate: 1 CO_2 + 1 NADH. Matrix.
Krebs cycle (C1.2.12)	Per turn: 2 CO_2 , 3 NADH, 1 FADH_2 , 1 ATP. Key intermediates: citrate (6C), oxaloacetate (4C). Matrix.
ETC and proton gradient (C1.2.13/14)	$\text{NADH} \rightarrow$ Complex I, $\text{FADH}_2 \rightarrow$ ubiquinone (skips I). H^+ pumped at I, III, IV into IMS. Gradient = proton motive force.
Chemiosmosis (C1.2.15)	H^+ flows through ATP synthase $\rightarrow \text{ADP} + \text{P}_i \rightarrow \text{ATP}$. $\sim 3 \text{H}^+$ per ATP. $\text{NADH} \rightarrow \sim 3 \text{ATP}$, $\text{FADH}_2 \rightarrow \sim 2 \text{ATP}$. O_2 = terminal electron acceptor at Complex IV. $\text{O}_2 + 4\text{e}^- +$
Role of O_2 (C1.2.16)	$4\text{H}^+ \rightarrow 2\text{H}_2\text{O}$. Without O_2 : ETC stops, NAD^+ runs out, Krebs stops.
Lipids vs carbohydrates (C1.2.17)	Lipids: higher energy per gram, more C-H bonds, less O already bound. Fatty acids $\rightarrow$ Acetyl-CoA via beta-oxidation. Glycolysis and anaerobic respiration use carbohydrates ONLY.

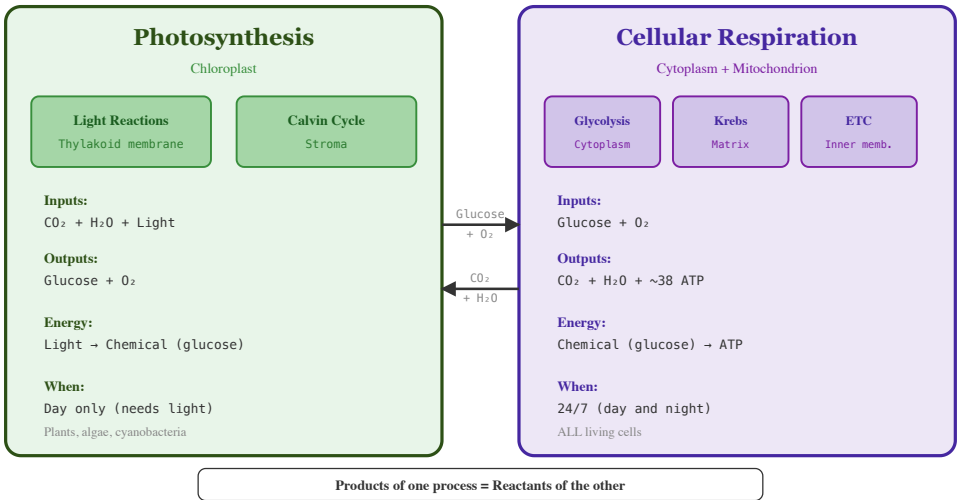
IB TIP

Tip: Print this checklist and tick each box as you can explain it from memory with no notes. Any unticked item = revision priority.

Section 7: Photosynthesis vs Cellular Respiration — Side-by-Side Comparison

These two processes are the **inverse** of each other. Understanding how they connect is one of the most tested concepts in IB Biology.

Overview Comparison



Photosynthesis and Cellular Respiration are inverse processes — they drive the carbon and oxygen cycles on Earth

Detailed Comparison Table

Feature	Photosynthesis	Cellular Respiration
Overall equation	$6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$	$\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \sim 38 \text{ ATP}$
Energy conversion	Light energy $\rightarrow$ chemical energy	Chemical energy $\rightarrow$ ATP
Organelle	Chloroplast	Mitochondrion (+ cytoplasm)
Organisms	Plants, algae, cyanobacteria	ALL living cells
When	Day only (requires light)	24/7 (day and night)
Gas exchange	Takes in CO_2 , releases O_2	Takes in O_2 , releases CO_2
Water	Consumed (photolysis)	Produced (at ETC)
Glucose	Produced (Calvin cycle)	Consumed (glycolysis)
Electron carriers	NADPH (carries electrons)	NADH and FADH_2 (carry electrons)
ATP production method	Chemiosmosis (thylakoid)	Chemiosmosis (inner membrane) + substrate-level
H^+ gradient location	Thylakoid lumen (inside)	Intermembrane space
Key enzyme	RuBisCO (carbon fixation)	ATP synthase (ATP production)
Stages	Light reactions $\rightarrow$ Calvin cycle	Glycolysis $\rightarrow$ Link $\rightarrow$ Krebs $\rightarrow$ ETC

What They Share (Similarities)

Shared Feature	In Photosynthesis	In Respiration
Chemiosmosis	H ⁺ gradient across thylakoid membrane drives ATP synthase	H ⁺ gradient across inner mitochondrial membrane drives ATP synthase
Electron transport chain	Thylakoid membrane (PS II → PS I)	Inner mitochondrial membrane (Complexes I-IV)
ATP synthase	In thylakoid membrane	In inner mitochondrial membrane
Electron carriers	NADPH	NADH, FADH ₂
Compartmentalisation	Reactions separated between thylakoid and stroma	Reactions separated between matrix and inner membrane
CO₂ involvement	Fixed by RuBisCO	Released by decarboxylation

⚠ EXAM ALERT

The IB frequently asks: “**Compare and contrast photosynthesis and respiration.**”

Use this table structure in your answer. Always mention: (1) they are inverse reactions, (2) both use chemiosmosis and ATP synthase, (3) both have electron transport chains, (4) products of one are reactants of the other.

💡 IB TIP

Common MCQ trap: “Respiration only occurs at night.” This is FALSE — respiration occurs 24/7 in ALL living cells. During the day, plants do BOTH photosynthesis AND respiration simultaneously. The net gas exchange depends on the rate of each process.

IB Exam-Style Questions

Question 1 (4 marks)

Explain the events of the light-dependent reactions of photosynthesis, including the roles of Photosystem II, Photosystem I, and the electron transport chain.

► Markscheme

Question 2 (3 marks)

Outline the events of the Calvin cycle (light-independent reactions), including the roles of RuBisCO, ATP, and NADPH.

► Markscheme

Question 3 (4 marks)

Explain how ATP is synthesised by chemiosmosis in the mitochondrion during aerobic respiration.

► Markscheme

Question 4 (4 marks)

Compare and contrast aerobic respiration and anaerobic respiration (fermentation) in terms of oxygen requirement, ATP yield, products, and location.

► 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. **[Light Reactions]** During the light-dependent reactions of photosynthesis, what is the direct source of electrons that reduce NADP^+ to NADPH?
 - A. Carbon dioxide from the atmosphere
 - B. Water molecules split by photolysis at Photosystem II
 - C. Glucose oxidised in the stroma
 - D. ATP hydrolysis by ATP synthase
2. **[Krebs Cycle]** One molecule of acetyl-CoA (2 carbons) entering the Krebs cycle produces, per turn:
 - A. 2 ATP, 2 NADH, 1 FADH_2 , and 2 CO_2
 - B. 3 NADH, 1 FADH_2 , 1 ATP (or GTP), and 2 CO_2
 - C. 4 NADH, 2 FADH_2 , 2 ATP, and 4 CO_2
 - D. 1 NADH, 1 FADH_2 , 1 ATP, and 1 CO_2
3. **[Chemiosmosis]** Which statement correctly describes the role of ATP synthase in both photosynthesis and aerobic respiration?
 - A. It directly uses light energy to phosphorylate ADP in both processes
 - B. It uses the flow of protons (H^+) down their electrochemical gradient to drive ATP synthesis in both processes
 - C. It pumps protons against their gradient using ATP in both processes

D. It functions only in the mitochondria; a different enzyme makes ATP in chloroplasts

4. **[Glycolysis]** A student claims that glycolysis requires oxygen. This claim is:

A. Correct — glycolysis cannot proceed without oxygen as the terminal electron acceptor

B. Incorrect — glycolysis occurs in the cytoplasm and does not require oxygen; it produces a net gain of 2 ATP and 2 NADH per glucose

C. Partially correct — glycolysis requires oxygen only in eukaryotes

D. Incorrect — glycolysis only occurs in anaerobic conditions

5. **[Calvin Cycle]** In the Calvin cycle, ribulose biphosphate (RuBP) reacts with CO₂ to form glycerate-3-phosphate (GP). This reaction is catalysed by:

A. ATP synthase

B. Rubisco (RuBisCO)

C. NADP reductase

D. Phosphoglycerate kinase

6. **[Electron Transport Chain]** In the mitochondrial electron transport chain, what is the final electron acceptor?

A. NAD⁺

B. FAD

C. Carbon dioxide

D. Oxygen, forming water

7. **[Comparing Processes — Distractor]** A student writes: “Photosynthesis and cellular respiration are exact opposites — they share no common steps or structures.” This statement is:

A. Correct — the two processes are chemically and structurally entirely distinct

B. Incorrect — both processes use chemiosmosis, electron transport chains, and ATP synthase, though in different organelles

C. Partially correct — they share ATP synthase but use entirely different electron carriers

D. Incorrect — both processes occur in the mitochondria

8. **[Light Reactions]** The absorption spectrum of chlorophyll a shows peaks at approximately 430 nm and 680 nm. This means chlorophyll a:
- A. Reflects red and blue light most strongly, appearing green
 - B. Absorbs blue and red light most strongly, reflecting green light — which is why leaves appear green
 - C. Absorbs all wavelengths of visible light equally
 - D. Only absorbs light at exactly 430 nm and 680 nm; all other wavelengths pass through
9. **[Glycolysis and Link Reaction]** Glucose (C_6) is converted to pyruvate (C_3) in glycolysis. Pyruvate is then converted to acetyl-CoA (C_2) in the link reaction. What happens to the “missing” carbon?
- A. It is stored as glycogen in the cytoplasm
 - B. It is released as CO_2 by oxidative decarboxylation, with the electrons passed to NAD^+ to form NADH
 - C. It is used to regenerate RuBP in the Calvin cycle
 - D. It is converted to ATP directly
10. **[Chemiosmosis — Distractor]** A metabolic poison blocks ATP synthase completely but does NOT affect the electron transport chain. Predict the effect on the mitochondrial matrix:
- A. The proton gradient across the inner mitochondrial membrane would collapse immediately
 - B. The proton gradient would increase (protons continue to be pumped out but cannot flow back through ATP synthase), and ATP synthesis would stop
 - C. NADH and $FADH_2$ would no longer be oxidised by the ETC
 - D. The matrix would become alkaline as protons accumulate inside it

► Show Answers

November 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 November 2026 IB Biology HL Paper 2. Based on recent exam patterns (2022-2025), expect heavy weighting on: light-dependent vs light-independent reactions, limiting factors on photosynthesis, respirometry, and the relationship between photosynthesis and cellular respiration.

WORKED EXAMPLE

Question 1 [Light Reactions vs Calvin Cycle] [~8 marks]

Compare and contrast the light-dependent reactions and the light-independent reactions (Calvin cycle) of photosynthesis. In your answer, include:

- (a) The precise location of each set of reactions within the chloroplast.
- (b) The role of NADP^+ and ATP in linking the two stages.
- (c) Explain what would happen to the rate of the Calvin cycle if the light-dependent reactions were suddenly inhibited.

► Show Solution

WORKED EXAMPLE

Question 2 [Limiting Factors] [~6 marks]

A student investigates the rate of photosynthesis in an aquatic plant (Elodea) by counting oxygen bubbles produced per minute at different light intensities. The temperature is kept constant at 25 °C and CO_2 concentration is 0.04%.

- (a) Sketch a graph showing the expected relationship between light intensity and rate of photosynthesis. Label the axes and indicate the plateau region.
- (b) Explain why the rate of photosynthesis reaches a plateau even though light intensity continues to increase.
- (c) Suggest how the student could increase the maximum rate of photosynthesis beyond the plateau.

► Show Solution

WORKED EXAMPLE

Question 3 [Respirometer] [~6 marks]

A simple respirometer is used to measure the rate of aerobic respiration in germinating seeds. The apparatus contains a sealed tube with seeds, a KOH pellet to absorb CO₂, and a coloured liquid in a capillary tube.

- (a) Explain why the coloured liquid moves toward the seeds during the experiment.
- (b) Explain the purpose of the KOH pellet in the respirometer.
- (c) The experiment is repeated at 35 °C instead of 20 °C. Predict and explain the effect on the rate of movement of the liquid.

► 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
Photosynthesis: Investigate how plants produce energy	B1/C1: Light-dependent and light-independent reactions	Chloroplast structure, electron transport chain, Calvin cycle
Cellular Respiration: Measuring the effect of temperature	B1/C1: Glycolysis, Krebs cycle, oxidative phosphorylation	Q ₁₀ and enzyme activity at varying temperatures
Photosynthesis and Respiration: Energy for Life	B1/C1: Relationship between the two processes	ATP as energy currency, net gas exchange

How to use these simulations for IB exam prep:

- Use the Cellular Respiration simulation before tackling Paper 3 experimental design questions on rate of respiration
- The Photosynthesis simulation's graphing tools mirror what the IB expects in light-intensity/rate graphs
- Run the simulations multiple times varying one factor — this mirrors the IA investigation design requirement

