AP Biology Unit 3

Cellular Energetics

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EXAM WEIGHT	MCQs	FRQ APPEARANCE	SPRINT TIME
12–16%	7–10	Almost Every Year	~2.5 hours

Inside this pack

- **Quick Glance at every Unit topic with priority + format**
- **Topic-by-topic key traps, must-know rules, and exam frames**
- **Worked example questions on the highest-yield topics**

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AP Biology Unit 3 — Cellular Energetics

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and photosynthesis inputs/outputs cold — these are predictable points.

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Quick Glance — All Topics at a Glance

Topic	Priority	Exam Format	Key Trap / Must-Know
3.1 Enzymes	★★★	MCQ, Data	Enzymes lower Ea only — ΔG and equilibrium UNCHANGED
3.2 Enzyme Regulation	★★★	MCQ, Data, FRQ	Competitive: ↑K_m, same V_{max}. Noncompetitive: same K_m, ↓V_{max}
3.3 ATP & Redox	★★★	MCQ, FRQ	OIL RIG; $NADH/FADH_2$ carry electrons TO ETC — not ATP
3.4 Photosynthesis	★★★	MCQ, FRQ, Data	O_2 from H_2O (NOT CO_2); Calvin cycle needs light products
3.5 Cellular Respiration	★★★	MCQ, FRQ, Data	~90% ATP from ETC (not glycolysis); fermentation = NAD^+ regeneration only

Best last 2 day focus: inhibition graphs, stage tables

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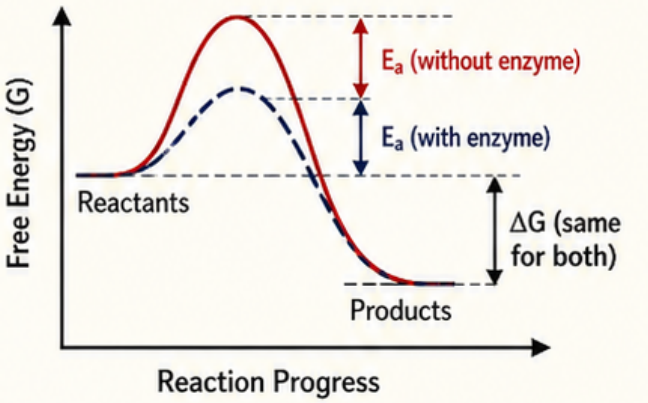
3.1 Enzymes

Catalysts, induced fit, and the biggest enzyme misconceptions

Core Definition

What Enzymes Do (and Don't)

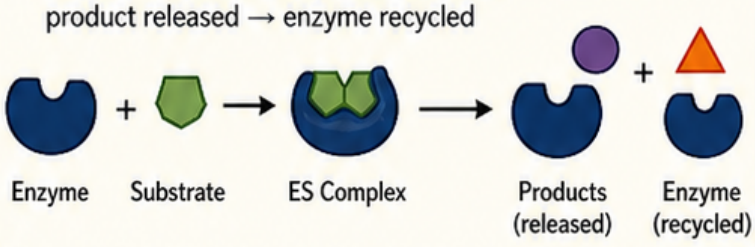
- **Biological catalysts** — speed up reactions; not consumed
- **Lower activation energy (E_a)** — energy to reach transition state
- **Do NOT change ΔG** (overall free energy difference reactants → products)
- **Do NOT change equilibrium** — only reach it faster
- **Do NOT make unfavorable** reactions favorable
- **Reusable**; specific to one substrate/reaction type



Binding Models

Induced Fit (Current Model)

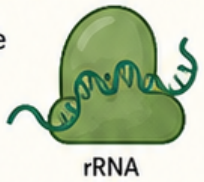
- **Lock-and-Key:** rigid active site; overly simplistic; NOT the preferred model
- **Induced Fit:** active site is flexible; changes shape when substrate binds → forms tighter enzyme–substrate complex → AP prefers this
- Active site = specific region where substrate binds
- Enzyme–substrate complex (ES complex) → product released → enzyme recycled



Special Cases

Cofactors, Coenzymes & Ribozymes

- **Cofactors:** inorganic ions required by enzyme (Mg^{2+}, Zn^{2+}, Fe^{2+})
- **Coenzymes:** organic helpers (NAD+, FAD, Coenzyme A)
- **Ribozymes:** RNA molecules that catalyze reactions — ribosomal rRNA catalyzes peptide bond formation (evidence for RNA world hypothesis)
- Most enzymes are proteins, but not all



Exam Sniper

- **Energy diagram MCQ:** identify E_a with/without enzyme, ΔG of reaction (same both curves), and which curve is enzyme-catalyzed (lower peak)
- **MCQ trap:** "The enzyme makes the reaction more thermodynamically favorable." → FALSE. Enzyme only lowers E_a peak, not ΔG endpoints
- **MCQ:** "Which of the following is an example of a ribozyme?" → rRNA in the ribosome (catalyzes peptide bond formation)
- **FRQ connection:** induced fit explains why inhibitors that bind the active site (competitive) or allosteric site (noncompetitive) affect enzyme function by altering shape

Trap Alert

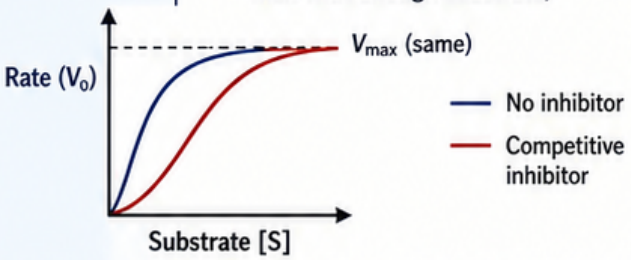
- Enzymes do NOT change ΔG — they only lower E_a
- Enzymes do NOT shift equilibrium — they just get there faster
- The induced-fit model is the AP-preferred model, not lock-and-key

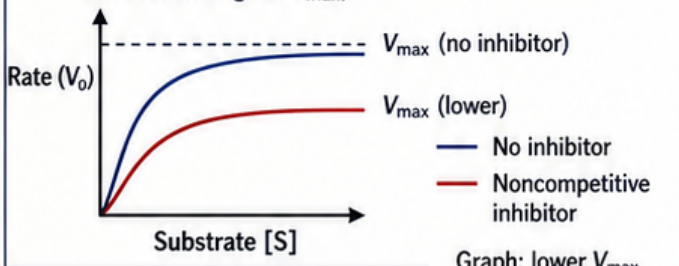
3.2 Enzyme Regulation & Environmental Impacts

Competitive vs. noncompetitive inhibition, pH/temperature, and feedback control

1 Competitive vs. Noncompetitive Inhibition — Graph Critical

	Competitive Inhibition	Noncompetitive Inhibition
Where inhibitor binds	Inhibitor binds active site (mimics substrate)	Inhibitor binds allosteric site (not active site)
Effect of more substrate	Competes directly with substrate for active site	Changes enzyme shape → active site distorted
K_m	Can be overcome by ↑ substrate concentration	Adding more substrate does NOT overcome it
V_{max}	K_m ↑ (apparent — need more substrate for same rate)	K_m unchanged (affinity for substrate same)
Graph clue	V_{max} unchanged (can still reach max with enough substrate)	V_{max} ↓ (even saturating enzyme can't reach original V_{max})
Examples	drugs that mimic substrate (e.g., ACE inhibitors)	allosteric inhibitors; heavy metal poisoning (Pb^{2+}, Hg^{2+})



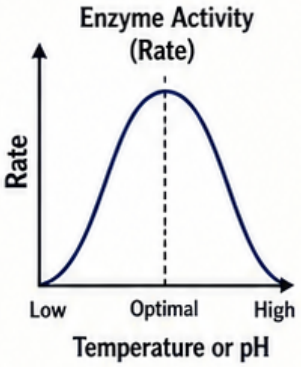


Graph: lower V_{max}, same K_m (same curve shape, lower plateau)

2 Environmental Effects

Temperature & pH

- **Optimal temperature:** fastest rate; above optimal → denaturation → loss of function (irreversible)
- **Optimal pH:** each enzyme has a specific pH optimum (pepsin pH 2 in stomach; trypsin pH 8 in small intestine)
- **Above/below optimum:** H-bonds and ionic bonds in enzyme broken → active site changes shape → substrate can't bind
- **Low temperature:** slows reaction but does NOT denature enzyme (reversible when warmed)



3 Metabolic Control

Allosteric Regulation & Feedback Inhibition

- **Allosteric regulation:** molecule binds site OTHER than active site → conformational change → activates or inhibits enzyme
- **Feedback inhibition:** end product of a pathway inhibits an enzyme earlier in the same pathway → prevents overproduction; saves energy
- **Example:** ATP inhibits phosphofructokinase (PFK) in glycolysis when energy is abundant
- **Allosteric activators:** increase enzyme activity by stabilizing active conformation

4 Exam Sniper

- Given a rate vs [substrate] graph: same V_{max} + right shift = competitive; lower V_{max} = noncompetitive
- If inhibitor still works at very high substrate concentration → noncompetitive
- High amino acid X inhibiting first enzyme in its own pathway = feedback inhibition
- Sharp drop above 45°C = denaturation disrupting 3° structure and active site shape

5 Graph MCQ

With inhibitor present, V_{max} is unchanged but K_m is doubled. What type of inhibition is this, and how does it work?

Answer: Competitive inhibition — inhibitor binds the active site and competes with substrate; excess substrate can displace it, so V_{max} stays the same but apparent K_m increases.

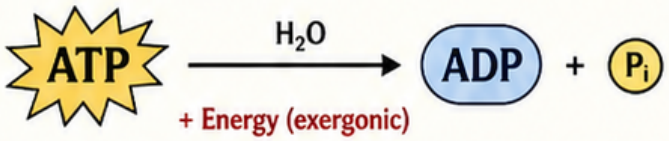
3.3 Cellular Energy — ATP, Thermodynamics & Redox

ATP, ΔG, OIL RIG, and electron carriers

Energy Currency

ATP — The Universal Currency

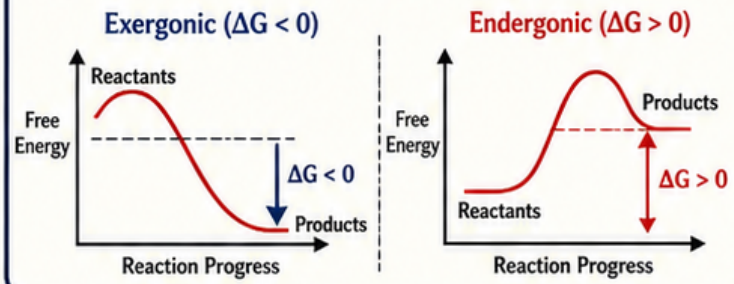
- ATP = adenosine triphosphate = adenine + ribose + 3 phosphate groups (a nucleotide!)
- **Hydrolysis:** ATP → ADP + P_i + energy (exergonic; ~7.3 kcal/mol released)
- **Synthesis:** ADP + P_i + energy → ATP (endergonic; phosphorylation)
- ATP is not long-term storage — recharged continuously
- **Three types of work:** mechanical, transport, chemical



Thermodynamics

ΔG — Free Energy

- **Exergonic (ΔG < 0):** releases free energy; spontaneous; products have less energy than reactants → cellular respiration, ATP hydrolysis
- **Endergonic (ΔG > 0):** requires energy input; not spontaneous → photosynthesis, ATP synthesis, biosynthesis
- **Energy coupling:** exergonic reaction (ATP hydrolysis) drives endergonic reactions
- Enzymes lower Ea but do NOT change ΔG



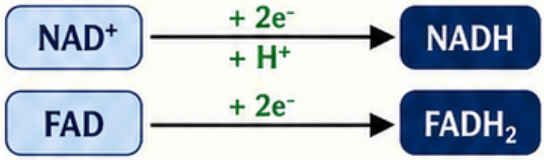
Must Memorize

OIL RIG — Redox Reactions

- **OIL RIG:** Oxidation Is electron Loss; Reduction Is electron Gain
- **Oxidation:** lose electrons → often lose H+ too in biology
- **Reduction:** gain electrons → often gain H+
- **Oxidizing agent:** causes oxidation (is itself reduced) → NAD^+, FAD, O_2
- **Reducing agent:** causes reduction (is itself oxidized) → glucose, NADH
- Glucose is oxidized in respiration; CO_2 is reduced in photosynthesis

Electron Carriers

NADH & $FADH_2$



- NAD^+: oxidized form; accepts 2 electrons + H^+ → becomes NADH
- FAD: oxidized form; accepts 2 electrons → becomes $FADH_2$
- NADH and $FADH_2$ carry electrons to the ETC
- ETC uses electron energy to pump H^+ → drives ATP synthase
- NADH yields ~2.5 ATP; $FADH_2$ yields ~1.5 ATP at the ETC
- In photosynthesis: $NADP^+$ → NADPH

Exam Sniper

- In cellular respiration, glucose is oxidized and oxygen is reduced
- Endergonic examples: photosynthesis, ATP synthesis, protein synthesis
- NADH's main role in respiration: carry electrons to the ETC, where they drive proton pumping and ATP synthesis
- Remember: carriers transport electrons, **not** ATP

3.4 Photosynthesis

Light reactions and the Calvin cycle — inputs, outputs, and locations

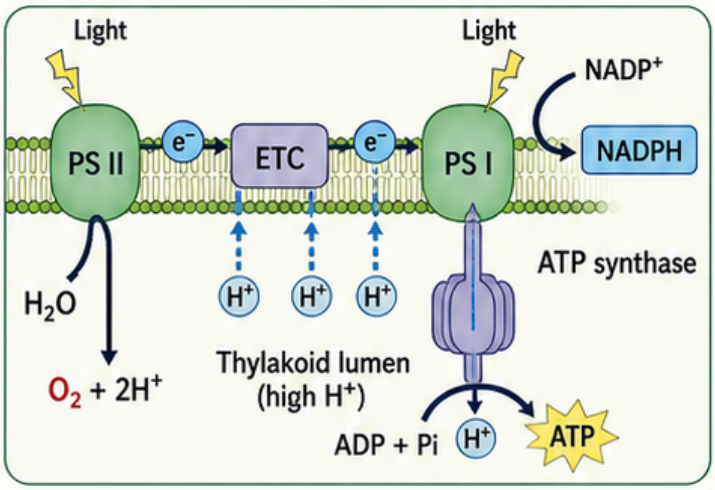
Stage-by-Stage Breakdown — Master This Table

Stage	Location	Inputs	Outputs	Key Point
Light Reactions (also: Light-Dependent)	Thylakoid membrane (in grana)	Light energy, H_2O, ADP+Pi, $NADP^+$	ATP, NADPH, O_2	Water is split (photolysis) → releases O_2; PS II → PS I → NADPH; ATP via chemiosmosis
Calvin Cycle (also: Carbon Fixation)	Stroma of chloroplast	CO_2, ATP, NADPH	G3P (→ used to build glucose), ADP+Pi, $NADP^+$	Fixes carbon (CO_2 → organic); uses ATP + NADPH from light reactions; enzyme = RuBisCO

Light Reactions — Critical Details

What Happens at the Thylakoid

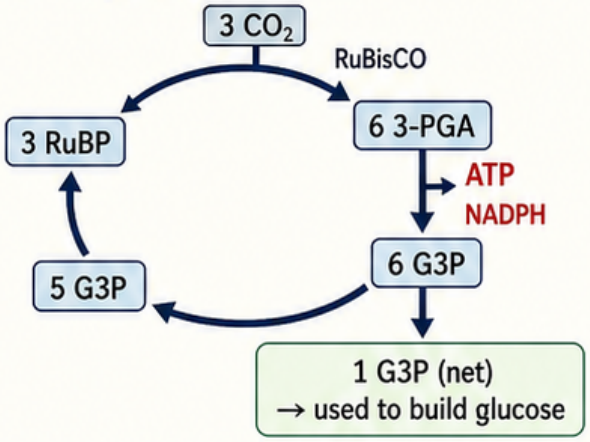
- Photosystem II (PS II): absorbs light → energizes electrons → water split ($H_2O \rightarrow O_2 + 2H^+ + 2e^-$)
- Electrons travel down ETC → H^+ pumped into thylakoid lumen (high H^+ inside)
- Photosystem I (PS I): re-energizes electrons with more light → electrons used to reduce $NADP^+$ → NADPH
- H^+ flows back through ATP synthase → ATP synthesized (chemiosmosis)
- O_2 comes from H_2O, NOT CO_2 — proven by ^{18}O isotope experiments



Calvin Cycle — Critical Details

What Happens in the Stroma

- CO_2 is fixed by enzyme RuBisCO
- 3 CO_2 + 3 RuBP → 6 3-carbon molecules → reduced to G3P
- G3P used to build glucose, amino acids, fatty acids
- Some G3P regenerates RuBP (keeps cycle running)
- "Light-independent" is misleading — Calvin cycle needs ATP + NADPH from light reactions. It stops in darkness when these run out
- 3 turns of cycle fix 3 CO_2 → 1 net G3P (one half of glucose)

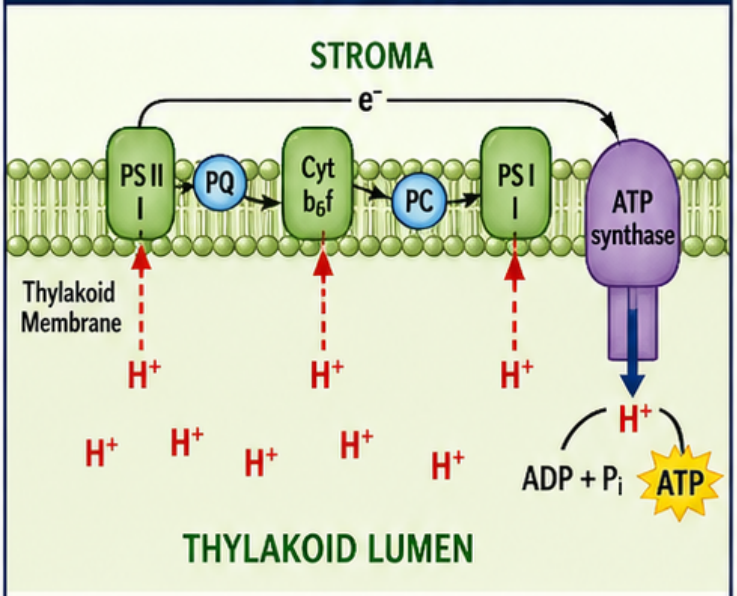


Most tested fact: O_2 released during photosynthesis comes from H_2O, not CO_2.

3.4 Photosynthesis — Chemiosmosis & Must-Knows

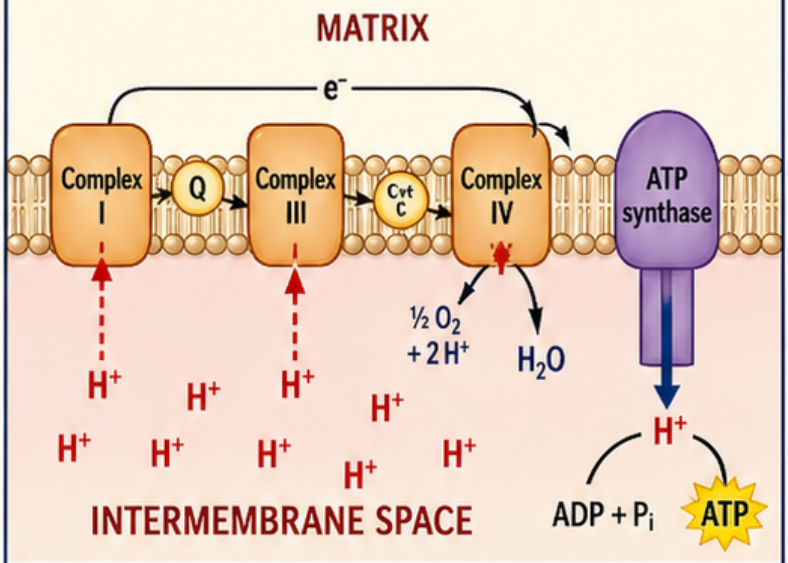
The ATP engine in chloroplasts — and how it compares with mitochondria

Chemiosmosis in Chloroplasts — The ATP Engine



- ETC pumps H^+ INTO the thylakoid lumen (from stroma)
- High H^+ inside thylakoid → concentration gradient
- H^+ flows OUT through ATP synthase in the thylakoid membrane → ATP synthesized in the stroma
- ATP + NADPH are used by the Calvin cycle

Compare with Mitochondria



- ETC pumps H^+ INTO the intermembrane space (from matrix)
- High H^+ in intermembrane space → concentration gradient
- H^+ flows BACK through ATP synthase in the inner membrane → ATP synthesized in the matrix
- O_2 is the terminal electron acceptor → H_2O formed

Feature	Chloroplast	Mitochondrion
Gradient Space	Thylakoid Lumen	Intermembrane Space
ATP Made In	Stroma	Matrix

Exam Sniper

- Source of O_2 released during photosynthesis? → Water split by PS II
- Calvin cycle slows in dark because ATP and NADPH from light reactions stop being produced
- Increasing light, CO_2, temperature up to optimun, and water can increase photosynthesis rate
- Calvin cycle location = stroma, not thylakoid membrane
- ATP synthase in photosynthesis makes ATP as H^+ flows from lumen to stroma

Trap Alert

- O_2 comes from H_2O, NOT CO_2
- Calvin cycle is not truly a "dark reaction" because it needs ATP and NADPH
- Plants do cellular respiration too, 24 hours a day
- PS II comes BEFORE PS I

3.5 Cellular Respiration

The 4 stages — location, inputs, outputs, and ATP yield

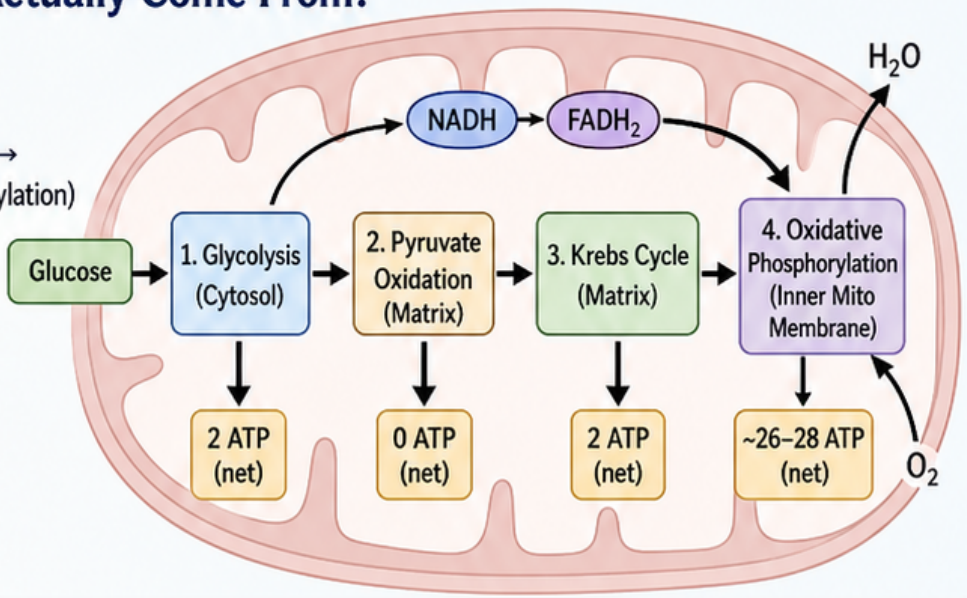
The 4 Stages — Master This Table

Stage	Location	O_2 Needed?	Inputs	Direct Outputs	Net ATP
1. Glycolysis	Cytosol	No	Glucose (1)	2 pyruvate, 2 NADH, 2 ATP net	**2 ATP**
2. Pyruvate Oxidation (pyruvate → acetyl-CoA)	Mitochondrial matrix	Yes (O_2 indirectly)	2 pyruvate, CoA, NAD^+	2 acetyl-CoA, 2 NADH, 2 CO_2	**0 ATP**
3. Krebs Cycle (Citric acid cycle)	Mitochondrial matrix	Yes (indirectly)	2 acetyl-CoA, H_2O, NAD^+, FAD	6 NADH, 2 $FADH_2$, 2 ATP, 4 CO_2	**2 ATP**
4. Oxidative Phosphorylation (ETC + ATP synthase)	Inner mitochondrial membrane	Yes — O_2 is terminal e^- acceptor	10 NADH, 2 $FADH_2$, O_2	~26–28 ATP, H_2O	**~26–28 ATP**

Critical Concept

Where Does ATP Actually Come From?

- Glycolysis + Krebs: only 4 ATP total (substrate-level phosphorylation)
- NADH + $FADH_2$ carry electrons to ETC → produce ~26–28 ATP (oxidative phosphorylation)
- ~90% of ATP from ETC / oxidative phosphorylation
- H^+ gradient drives ATP synthase — chemiosmosis
- NADH yields ~2.5 ATP; $FADH_2$ yields ~1.5 ATP (enters ETC lower down)
- O_2 accepts electrons at the end → forms H_2O



Glycolysis is the only ATP-producing stage that occurs outside the mitochondrion.

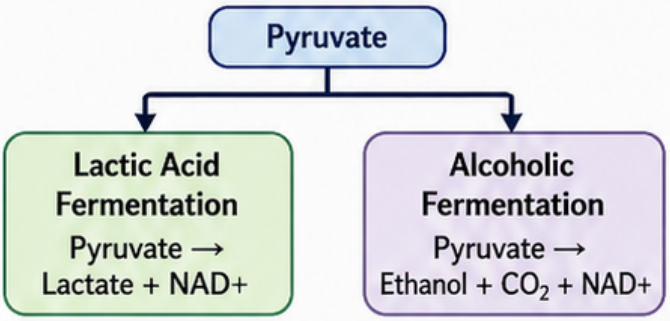
3.5 Cellular Respiration — Fermentation, Carbon Tracking & ETC Traps

What happens without oxygen, where CO_2 is released, and the classic uncoupler question

Without Oxygen

Fermentation — The Backup Plan

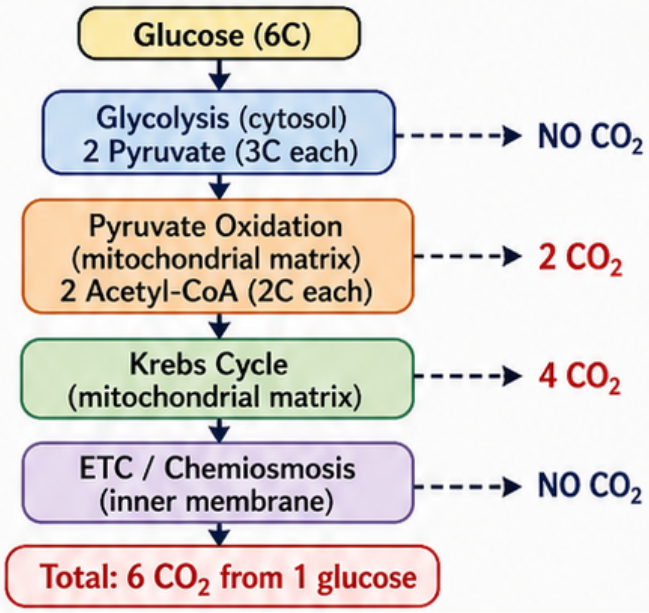
- Occurs when O_2 is absent (anaerobic conditions)
- Glycolysis still runs → produces 2 ATP + 2 NADH + 2 pyruvate
- Fermentation's ONLY purpose: regenerate NAD^+ from NADH so glycolysis can continue
- NO additional ATP produced in fermentation steps themselves
- Two types: lactic acid fermentation (animals, some bacteria: pyruvate → lactate + NAD^+); alcoholic fermentation (yeast: pyruvate → ethanol + CO_2 + NAD+)
- Total ATP = only 2 ATP (from glycolysis)



Where CO_2 is Released

Tracking Carbon

- Glycolysis: NO CO_2 released
- Pyruvate oxidation: 2 CO_2 released
- Krebs cycle: 4 CO_2 released
- ETC / chemiosmosis: NO CO_2 released
- Total: 6 CO_2 from 1 glucose
- All carbon from glucose ends up as CO_2 by end of Krebs



Exam Sniper

- Role of ETC in ATP synthesis: electrons from $NADH/FADH_2$ pass through inner membrane proteins → energy pumps H^+ into intermembrane space → H^+ back through ATP synthase makes ATP; O_2 accepts electrons and becomes H_2O
- If mitochondria are destroyed, glycolysis can still occur
- Yeast produces ethanol to regenerate NAD^+ so glycolysis can continue
- In yeast, aerobic conditions produce more CO_2 than anaerobic fermentation
- If ATP synthase is blocked, oxidative phosphorylation is directly affected

Trap Alert

- ~90% of ATP comes from oxidative phosphorylation, not glycolysis or Krebs
- Fermentation makes NO extra ATP — only regenerates NAD+
- Glycolysis happens in the cytosol
- O_2 is the terminal electron acceptor, not the energy source itself
- CO_2 is produced in pyruvate oxidation and Krebs, not glycolysis or ETC

Highest-Frequency MCQ

A proton uncoupler makes the inner mitochondrial membrane permeable to H^+. What happens?

The ETC can continue, but ATP synthesis decreases because the H^+ gradient collapses. Oxygen may still be consumed, and much of the energy is released as heat.

Sprint Practice — Mixed Questions

Cross-topic AP-style reasoning

1 Cross-Topic MCQ — Photosynthesis + Respiration

A plant is kept in a sealed container in bright light. Initially, CO_2 decreases and O_2 increases. After several hours, gas concentrations stabilize with no further net change. Which explanation best accounts for the stabilization?

(A) The plant ran out of chlorophyll and can no longer photosynthesize

(B) Photosynthesis rate equals cellular respiration rate, so net O_2 and CO_2 exchange is zero

(C) The Calvin cycle stopped because there is no CO_2 left to fix

(D) The plant switched entirely to anaerobic fermentation

Answer:

(B) — Plants perform both photosynthesis and respiration. As CO_2 drops and O_2 rises, photosynthesis slows until it equals respiration. The system reaches the compensation point, so net gas exchange is zero.

2 Data Analysis — Enzyme Inhibition

Without inhibitor: V_{max} = 100 μmol/min, K_m = 4 mM.
With inhibitor X: V_{max} = 100 μmol/min, K_m = 12 mM.
With inhibitor Y: V_{max} = 50 μmol/min, K_m = 4 mM.
What are X and Y?

(A) X = noncompetitive; Y = competitive

(B) X = competitive; Y = noncompetitive

(C) Both are competitive inhibitors

(D) X = allosteric activator; Y = feedback inhibitor

Answer:

(B) — X is competitive because V_{max} is unchanged but K_m increases. Y is noncompetitive because K_m is unchanged but V_{max} decreases.

3 FRQ-Style Photosynthesis Mechanism

A scientist blocks Photosystem II but leaves Photosystem I functional. Predict what happens to O_2 production, NADPH production, and the Calvin cycle.

(A) O_2 decreases; NADPH increases; Calvin cycle increases

(B) O_2 production stops; NADPH production stops; Calvin cycle cannot proceed

(C) O_2 production stops; NADPH continues normally; Calvin cycle unaffected

(D) All three decrease proportionally but do not stop

Answer:

(B) — No water splitting means no O_2. Without electrons from PS II, PS I cannot make NADPH. Without ATP/NADPH from the light reactions, the Calvin cycle cannot continue.

Tip: In Unit 3, always track location, inputs/outputs, electron flow, and whether ATP comes from substrate-level phosphorylation or chemiosmosis.

Final Review — Exam Traps + Checklist

Use this page the night before and the morning of the exam

1. Unit 3 High-Frequency Exam Traps

- Plants do NOT "only do photosynthesis" — they also respire 24/7. At night: only respiration. In bright light: photosynthesis rate > respiration. Compensation point = equal rates.
- O_2 in photosynthesis comes from H_2O, NOT CO_2. PS II splits water; carbon from CO_2 goes into sugar.
- Fermentation produces NO additional ATP beyond glycolysis; its purpose is NAD^+ regeneration.
- ~90% of ATP comes from the ETC / oxidative phosphorylation, NOT glycolysis or Krebs.
- Competitive inhibitor: V_{max} unchanged, K_m increased. Noncompetitive: V_{max} decreased, K_m unchanged.
- The Calvin cycle is not truly a "dark reaction"; it requires ATP and NADPH from light reactions.
- Glycolysis is in the cytosol, not the mitochondrion; prokaryotes can do glycolysis.
- Enzymes do NOT change ΔG or equilibrium — only E_a.

2. Pre-Exam 10-Minute Checklist

A. Enzymes & Regulation (3.1–3.2)

- ☐ Enzymes lower E_a only; ΔG and equilibrium unchanged
- ☐ Induced fit = preferred model
- ☐ Competitive inhibitor: active site, ↑K_m, V_{max} unchanged, overcome by more substrate
- ☐ Noncompetitive inhibitor: allosteric site, ↓V_{max}, K_m unchanged
- ☐ Feedback inhibition = end product inhibits first enzyme
- ☐ Above optimum temperature = denaturation; cold only slows

B. ATP & Redox (3.3)

- ☐ OIL RIG
- ☐ Glucose oxidized in respiration; CO_2 reduced in photosynthesis
- ☐ NADH and $FADH_2$ carry electrons to ETC; $NADP^+ \rightarrow NADPH$ in photosynthesis
- ☐ Exergonic = ΔG < 0; Endergonic = ΔG > 0

C. Photosynthesis (3.4)

- ☐ Light reactions: thylakoid membrane; inputs light, H_2O, ADP+Pi, $NADP^+$; outputs ATP, NADPH, O_2
- ☐ Calvin cycle: stroma; inputs CO_2, ATP, NADPH; outputs G3P, ADP+Pi, $NADP^+$
- ☐ O_2 released comes from H_2O
- ☐ PS II → ETC → PS I → NADPH; ATP synthase in thylakoid membrane
- ☐ Calvin cycle stops in darkness because ATP/NADPH run out

D. Cellular Respiration (3.5)

- ☐ Glycolysis: cytosol, 2 pyruvate + 2 ATP + 2 NADH
- ☐ Pyruvate oxidation: matrix, 2 acetyl-CoA + 2 CO_2 + 2 NADH
- ☐ Krebs: matrix, 4 CO_2 + 6 NADH + 2 $FADH_2$ + 2 ATP
- ☐ ETC + ATP synthase: inner membrane; O_2 terminal acceptor; ~26–28 ATP
- ☐ ~90% ATP from ETC
- ☐ Fermentation = 0 extra ATP; purpose = regenerate NAD^+
- ☐ CO_2 released in pyruvate oxidation and Krebs only

3. Final Sprint Strategy for Unit 3

Top 5 must-master concepts: inhibition graph reading, photosynthesis stage I/O, respiration 4-stage table, chemiosmosis in both organelles, fermentation = NAD^+ only

FRQ templates: trace electrons from glucose to ATP synthesis; explain why Calvin cycle stops in dark; compare competitive vs noncompetitive inhibition using a graph

AP focus: do NOT memorize every glycolysis/Krebs intermediate; focus on big-picture concepts and relative ATP yield

Connections: Unit 1 ATP; Unit 2 membrane gradients; Unit 4 ATP in signaling; Unit 5 enzymes in DNA replication

If you can explain every checked item out loud, you're ready.

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