Unit 4 · Plant Respiration

STUDY NOTES

WHAT NEB'S GRADE 12 EXAM ASKS

- **CDC's grid (2078):** Plant Physiology (Units 2–6 together): 11 of 75 marks; 3 MCQs (knowledge, application, higher ability) and 1 long question (8 marks: knowledge 1, understanding 3, application 2, higher ability 2)
- **The paper:** Botany 37 + Zoology 38; each part: MCQs × 1 (5 Botany, 6 Zoology) · 4 short × 4 · 2 long × 8; one OR in each short and long group; 3 hours; 1 mark per expected point
- **CDC's model paper:** long: how glycolysis and the Krebs (TCA) cycle are linked; a detailed flow chart of the Krebs cycle (4 + 4)
- **MCQ (1 mark)**
  - power-house of the cell; aerobic: complete oxidation
  - site of anaerobic respiration; end product of glycolysis
  - net ATP of glycolysis; EMP pathway; link reaction
  - 38 ATP; citric acid; 3 ATP per $NADH_2$
  - step common to both; oxysome; matrix
  - fermentation without CO_2; yeast
- **Short and long (in parts)**
  - cellular respiration and its significance
  - aerobic vs anaerobic
  - glycolysis: definition, significance; EMP pathway with a diagram
  - link reaction; Krebs cycle with a figure
  - fermentation and its types; anaerobic respiration and its significance
  - factors affecting respiration (external: describe any two)

Key terms

Cellular respiration: breakdown (oxidation) of food in the cell to release energy, trapped as **ATP**; **catabolic**.

ATP: adenine + ribose + 3 phosphates; the cell's **energy currency**; ATP + H_2O → ADP + P_i + ~30.5 kJ/mol.

Phosphorylation: making ATP from ADP + P_i.

Substrate-level phosphorylation: an enzyme passes phosphate straight from a substrate to ADP.

Oxidative phosphorylation (terminal oxidation): ATP made with the energy of electrons passing to oxygen.

Aerobic respiration: uses O_2; food **completely** oxidized to CO_2 + H_2O.

Anaerobic respiration: no O_2; food **partly** oxidized to alcohol or an acid; called **fermentation** in microbes.

Glycolysis (EMP pathway): glucose → 2 pyruvic acid, in the cytoplasm.

Link reaction: pyruvic acid → acetyl CoA + CO_2 + $NADH_2$ (pyruvate dehydrogenase).

Krebs cycle (citric acid, TCA cycle): acetyl CoA oxidized to CO_2 in the matrix (Hans Krebs, 1937).

Electron transport chain: carriers in the inner mitochondrial membrane passing electrons to O_2.

Chemiosmosis: H^+ flowing back through **ATP synthase** (F_0–F_1 particle, **oxysome**) makes ATP.

Q_{10}: factor by which a rate rises for 10 °C; ~2 (**van 't Hoff's rule**).

Extinction point: O_2 level above which anaerobic respiration stops.

Wound respiration: faster respiration at a cut or bruise.

Respiration

- $C_6H_{12}O_6 + 6\,O_2 \longrightarrow 6\,CO_2 + 6\,H_2O$ + 2870 kJ (686 kcal) per mole; ~16 kJ (3.8 kcal) per g
- not burning: body temperature, ~20 enzyme steps, ~⅓ caught as ATP, rest heat

	Photosynthesis	Respiration
sugar	built	broken down
process	anabolic	catabolic
energy	stored	released
where	chloroplasts, green cells	cytoplasm, mitochondria, all cells
when	light only	day and night
gases	CO_2 in, O_2 out	O_2 in, CO_2 out
dry weight	increases	decreases

Significance

- ATP for building cellulose, starch, proteins, lipids, nucleic acids
- energy for division, growth, repair, mineral uptake, phloem loading, movements

- building blocks: α-ketoglutaric acid → glutamic acid (→ chlorophyll); OAA → aspartic acid; acetyl CoA → fatty acids
- balance of CO_2 and O_2 with photosynthesis
- industry (fermentation): curd, cheese, bread, brewing, vinegar, tanning, retting jute, antibiotics, vitamins, ethanol
- germinating seeds in a flask warm up; boiled seeds don't; lime water turns milky

	Aerobic	Anaerobic
oxygen	needed	not needed
occurs in	all higher plants, animals, most microbes	some bacteria, yeast, cells short of O_2
breakdown	complete, $CO_2 + H_2O$	partial: alcohol or acid
steps	glycolysis, link, Krebs, ETC	glycolysis, fermentation
site	cytoplasm, mitochondria	cytoplasm only
energy per mole	2870 kJ	~200–235 kJ
ATP per glucose	38	2
water	formed	not formed

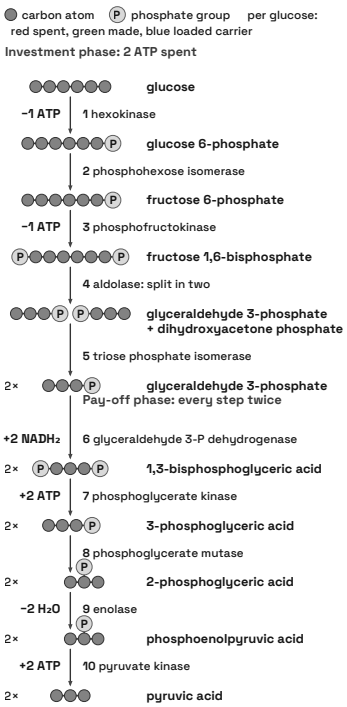
Stage	Where	Out (per glucose)
glycolysis	cytoplasm	2 pyruvic acid, 2 ATP (net), 2 $NADH_2$
link reaction	matrix	2 acetyl CoA, 2 CO_2, 2 $NADH_2$
Krebs cycle	matrix	4 CO_2, 2 ATP (GTP), 6 $NADH_2$, 2 $FADH_2$
ETC	inner membrane	water, most ATP

Glycolysis (EMP pathway)

- **Embden, Meyerhof, Parnas** (1930s); cytoplasm; every living cell; no O_2, no CO_2; 10 enzyme steps; 1, 3, 10 one way (control points)
- glucose + 2 NAD + 2 ADP + 2 P_i → 2 pyruvic acid + 2 $NADH_2$ + 2 ATP

Step	Change	Enzyme	Per glucose
1	glucose → glucose 6-P	hexokinase	−1 ATP
2	→ fructose 6-P	phosphohexose isomerase	
3	→ fructose 1,6-bisP	phosphofructokinase	−1 ATP
4	→ G3P (PGAL) + DHAP	aldolase	
5	DHAP → G3P	triose phosphate isomerase	
6	2 G3P + P_i → 2 1,3-bisPGA	G3P dehydrogenase	+2 $NADH_2$
7	→ 2 3-PGA	phosphoglycerate kinase	+2 ATP
8	→ 2 2-PGA	phosphoglycerate mutase	
9	→ 2 PEP + 2 H_2O	enolase	
10	→ 2 pyruvic acid	pyruvate kinase	+2 ATP

- 4 ATP made (steps 7, 10, substrate-level), 2 used (1, 3) → **net 2 ATP**
- step 3 (phosphofructokinase): main control point; step 6: only oxidation



Glycolysis.

Significance

- first stage of aerobic and anaerobic respiration
- in every living thing; oldest pathway
- only ATP source without O_2

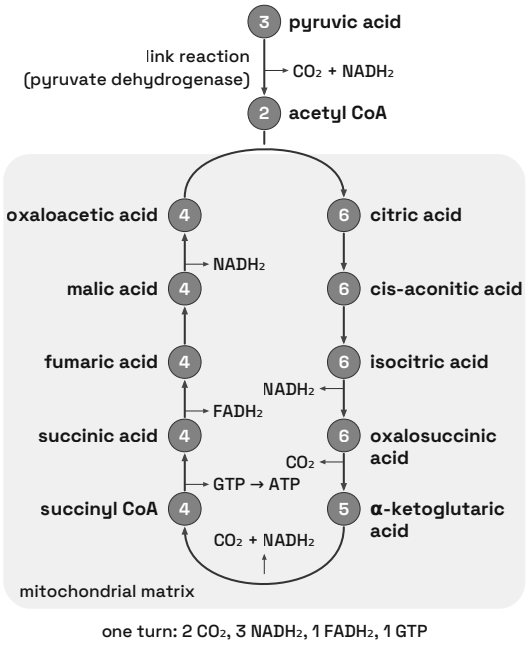
- $NADH_2$ → ETC; pyruvic acid → Krebs cycle
- intermediates build glycerol (from DHAP), amino acids

Link reaction and Krebs cycle

- **link**: pyruvic acid enters mitochondrion; **oxidative decarboxylation** (pyruvate dehydrogenase)
- 2 pyruvic acid + 2 CoA + 2 NAD → 2 **acetyl CoA** + 2 CO_2 + 2 $NADH_2$; first CO_2 of respiration
- **Krebs cycle**: matrix (succinate dehydrogenase in the inner membrane); OAA (4C) made again each turn

1. acetyl CoA (2C) + **OAA** (4C) + H_2O → **citric acid** (6C) + CoA (citrate synthase)
2. citric acid → **cis-aconitic acid** + H_2O (aconitase)
3. cis-aconitic + H_2O → **isocitric acid** (aconitase)
4. isocitric + NAD → **oxalosuccinic acid** + **$NADH_2$** (isocitrate dehydrogenase)
5. oxalosuccinic → **α-ketoglutaric acid** (5C) + **CO_2**
6. α-ketoglutaric + CoA + NAD → **succinyl CoA** (4C) + **CO_2** + **$NADH_2$** (α-ketoglutarate dehydrogenase)
7. succinyl CoA + GDP + P_i → **succinic acid** + CoA + **GTP** (→ ATP; succinyl CoA synthetase)
8. succinic + FAD → **fumaric acid** + **$FADH_2$** (succinate dehydrogenase)
9. fumaric + H_2O → **malic acid** (fumarase)
10. malic + NAD → **OAA** + **$NADH_2$** (malate dehydrogenase)

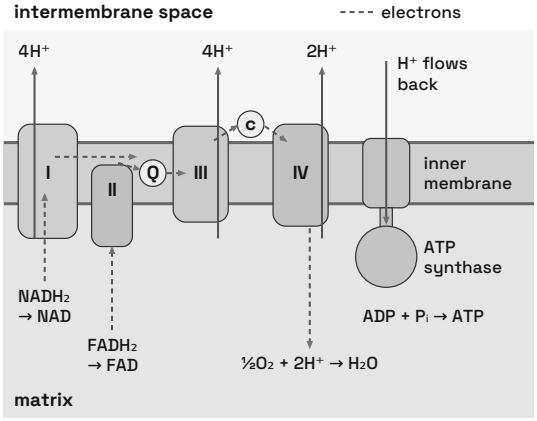
- per turn: 2 CO_2, 3 $NADH_2$, 1 $FADH_2$, 1 GTP; per glucose (2 turns): 4 CO_2, 6 $NADH_2$, 2 $FADH_2$, 2 ATP
- with the link reaction all 6 C leave as 6 CO_2



The Krebs cycle.

Electron transport chain

- inner mitochondrial membrane (cristae); takes 10 $NADH_2$ + 2 $FADH_2$
- $NADH_2$ → **complex I** → **coenzyme Q** → **complex III** (cyt bc_1) → **cytochrome c** → **complex IV** (cyt c oxidase) → **O_2**
- $FADH_2$ → **complex II** → coenzyme Q → …
- O_2 final acceptor: $\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$; the **only** stage using O_2; no O_2 → chain and Krebs cycle stop
- complexes I, III, IV pump H^+ **matrix** → **intermembrane space** (4, 4, 2 per $NADH_2$); complex II none
- H^+ flow back **into the matrix** through **ATP synthase** (F_0 base, F_1 head) → ATP: **chemiosmosis**



The electron transport chain.

ATP balance ($NADH_2$ = 3 ATP, $FADH_2$ = 2)

Stage	Direct	Carriers	From ETC	Total
glycolysis	2	2 $NADH_2$	6	8
link	0	2 $NADH_2$	6	6
Krebs	2	6 $NADH_2$, 2 $FADH_2$	22	24
total	**4**		**34**	**38**

- some cells: glycolysis $NADH_2$ gives 2 ATP each → 36
- modern measurements: ~2.5 and 1.5 per carrier → **about 30–32**; exam answer **38**
- ~9/10 of ATP from the ETC

Anaerobic respiration

- cytoplasm only: **glycolysis** → **fermentation** (pyruvic acid reduced by $NADH_2$)
- fermentation makes **no ATP**; it frees **NAD** so glycolysis goes on; 2 ATP per glucose

Alcoholic (yeast, some bacteria; flooded roots, inside fruits)

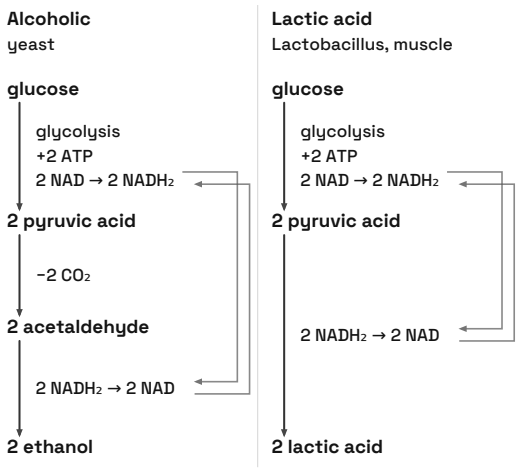
- $CH_3COCOOH \longrightarrow CH_3CHO + CO_2$ (pyruvate decarboxylase)
- $CH_3CHO + NADH_2 \longrightarrow C_2H_5OH + NAD$ (alcohol dehydrogenase)
- $C_6H_{12}O_6 \longrightarrow 2\,C_2H_5OH + 2\,CO_2 + 2$ ATP; bread, jaand, tongba (murcha), biofuel

Lactic acid (*Lactobacillus*; muscles in hard exercise)

- $CH_3COCOOH + NADH_2 \longrightarrow CH_3CHOHCOOH + NAD$ (lactate dehydrogenase); **no CO_2**
- curd (juju dhau), gundruk, sinki; muscle lactic acid → liver

Acetic acid (vinegar)

- yeast: sugar → ethanol; then *Acetobacter*: $C_2H_5OH + O_2 \longrightarrow CH_3COOH + H_2O$: needs air



Fermentation recycles NAD.

Significance

- energy where O_2 is short: hard-coated seeds, waterlogged roots, bulky fruits, sprinting muscle, microbes
- life without O_2 (bacteria, yeast)
- returns NAD to glycolysis
- industries: bread, alcohol, biofuel; curd, cheese, gundruk; vinegar; retting, tanning, biogas
- drawbacks: wasteful (2 ATP); toxic products

Factors affecting respiration

External

- **temperature**: most important; 5–30 °C rate doubles per 10 °C ($Q_{10} \approx 2$); above ~35 °C falls with time (enzymes denatured), stops ~45–50 °C; cold storage
- **oxygen**: final electron acceptor; low O_2 → anaerobic; **extinction point**; controlled-atmosphere storage
- **water**: dry seeds hardly respire; soaked seeds respire fast
- **light**: indirect: warms, makes substrate, opens stomata
- **CO_2**: high CO_2 slows respiration, closes stomata (Heath); slows germination

Internal

- **protoplasm**: meristem cells respire fastest
- **substrate**: glucose at once; starch, fat broken first; glucose drip for patients
- **age**: young cells faster
- **wounds**: wound respiration; cut potato, bruised mango spoil faster
- damp paddy heap heats up → O_2 runs out → anaerobic, sour; dry to 12–14% moisture

COMMON MISTAKES

✗ Plants don't respire in light
✓ every living cell respires day and night.

✗ Glycolysis takes place in the mitochondria
✓ in the **cytoplasm**.

✗ Glycolysis makes 4 ATP
✓ **net 2** (4 made, 2 used).

✗ First stable product of the Krebs cycle is OAA
✓ **citric acid**.

✗ CO_2 comes from glycolysis
✓ from the **link reaction and Krebs cycle**.

✗ H^+ pumped into the matrix
✓ **into the intermembrane space**; ATP made as they flow back.

✗ Fermentation makes extra ATP
✓ none; it regenerates NAD.

✗ Lactic acid fermentation gives CO_2
✓ **no CO_2**.

✗ Acetic acid fermentation is anaerobic
✓ its second step needs **oxygen**.