

The light-dependent reactions: the steps in order

Site: the thylakoid membranes of the chloroplast (stacked into grana); protons are pumped into the thylakoid lumen and flow back to the stroma, where the Calvin cycle runs. A photosystem is hundreds of pigment molecules funnelling light to a reaction centre: P680 in photosystem II, P700 in photosystem I (numbered in order of discovery, not of electron flow).

Step	What happens	Product
1 Light hits photosystem II	pigments pass energy to P680, which loses an excited electron to the primary acceptor	
2 Photolysis of water	$2\text{H}_2\text{O} \rightarrow 4\text{H}^+ + 4\text{e}^- + \text{O}_2$ on the lumen side; electrons refill P680; protons stay in the lumen	O ₂ released
3 Electron transport chain	primary acceptor $\rightarrow$ plastoquinone $\rightarrow$ cytochrome b6f complex $\rightarrow$ plastocyanin; the cytochrome complex pumps protons from stroma to lumen	proton gradient
4 Light hits photosystem I	P700 loses an excited electron; it is refilled by the electron from plastocyanin	
5 NADPH made	electron $\rightarrow$ ferredoxin $\rightarrow$ NADP ⁺ reductase: $\text{NADP}^+ + 2\text{e}^- + \text{H}^+ \rightarrow \text{NADPH}$	NADPH
6 Gradient builds	lumen pH about 5, stroma about 8: a thousandfold difference plus charge	
7 Chemiosmosis	protons flow back through ATP synthase, which joins $\text{ADP} + \text{P}_i \rightarrow \text{ATP}$ (photophosphorylation; about 3 H ⁺ per ATP)	ATP
8 To the stroma	ATP and NADPH drive the Calvin cycle, which returns ADP, P _i and NADP ⁺	

	Inputs	Outputs
Light-dependent (thylakoid membrane)	light; H ₂ O; ADP + P _i ; NADP ⁺	O ₂ ; ATP; NADPH
Calvin cycle (stroma)	CO ₂ ; ATP; NADPH	G3P ($\rightarrow$ glucose, sucrose, starch); ADP + P _i ; NADP ⁺

Per O₂ released: 2 water molecules split, 4 electrons travel the chain. Per glucose: the Calvin cycle needs 18 ATP and 12 NADPH.

The Z-scheme, and cyclic against non-cyclic flow

[] Electron energy against position: up at PSII (light in), down the chain (energy out, pumping protons), up at PSI (light in), a short fall to NADPH. Two photosystems because one photon cannot lift an electron from water all the way to NADPH

[] Non-cyclic: PSII and PSI, electrons from water, products ATP + NADPH + O₂. Cyclic: PSI only, the electron returns via ferredoxin to the cytochrome complex, ATP only; tops up ATP because the Calvin cycle needs more ATP than NADPH (18:12)

From

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The two stages compared, the mistakes, and a practice set

	Light-dependent	Light-independent (Calvin cycle)
Site	thylakoid membranes	stroma
Needs light directly	yes	no, but needs ATP and NADPH from the light stage
Key molecules	chlorophyll, photosystems, ETC, ATP synthase	RuBisCO, RuBP, G3P
Energy	light → chemical (ATP, NADPH)	chemical → sugar
Gas	releases O ₂	takes in CO ₂
Water	split	its hydrogen reaches the sugar via NADPH

In the stroma RuBisCO fixes CO₂ onto RuBP (5 C) giving two 3-PGA (3 C); ATP phosphorylates and NADPH reduces them to G3P; some G3P leaves to make glucose, sucrose, starch and cellulose, the rest is rebuilt into RuBP with more ATP. In darkness the cycle stops within seconds for lack of ATP and NADPH.

Mistakes

- [] Oxygen said to come from CO₂ (it comes from water)
- [] Photosystem I placed before II in the electron path
- [] ATP made 'by the electron transport chain' (the chain pumps protons; ATP synthase makes ATP by chemiosmosis)
- [] 'In the chloroplast' or 'in the stroma' instead of the thylakoid membrane
- [] NADH written for NADPH; the Calvin cycle said to run at night; glucose said to be made directly (the cycle makes G3P)

Curriculum	Where
US	AP Biology Unit 3; HS-LS1-5
England	A-level Biology: photolysis, photophosphorylation, Z-scheme, cyclic and non-cyclic; GCSE equations only
IB	C1.3 (HL detail)
Australia	Year 12 Biology
CBSE	Class 11 Photosynthesis in Higher Plants

Practice

- List the inputs and outputs of the light-dependent reactions and say where they occur.
- Write the equation for photolysis and say what happens to each product.
- Order these: plastocyanin, photosystem I, NADP⁺ reductase, photosystem II, plastoquinone, cytochrome b6f complex, ferredoxin.
- Explain how a proton gradient leads to ATP synthesis.
- Why does cyclic photophosphorylation make no oxygen and no NADPH?
- A plant is moved into the dark. Why does the Calvin cycle stop within seconds?

Answers

1. In: light, water, ADP + Pi, NADP⁺. Out: O₂, ATP, NADPH. Thylakoid membranes. 2. $2\text{H}_2\text{O} \rightarrow 4\text{H}^+ + 4\text{e}^- + \text{O}_2$; electrons refill P680, protons build the gradient, O₂ diffuses out. 3. PSII, plastoquinone, cytochrome b6f, plastocyanin, PSI, ferredoxin, NADP⁺ reductase. 4. Protons accumulate in the lumen; they flow down their gradient through ATP synthase, whose rotation joins ADP and Pi (chemiosmosis). 5. Only PSI is used and the electron returns to the chain, so no water is split (no O₂) and no electron reaches NADP⁺ (no NADPH); only protons are pumped, so only ATP is made. 6. Without light the light reactions stop, ATP and NADPH run out within seconds, and the reduction and regeneration steps of the cycle cannot proceed.