Photosynthesis

C1.3 · SL and HL

Why does a brighter lamp stop helping?

A plateau needs an energy pathway and a controlled test

Common C1.3: light-to-chemical energy, oxygen production, pigments, chromatography, spectra, limiting factors and carbon-dioxide enrichment.

All numerical datasets are invented for teaching; spectral curves are illustrative models rather than measured data.

Keep energy, carbon atoms and a measured gas rate as separate quantities.

AHL follows electrons, protons and recycled carbon

Different arrows represent different transfers

AHL content: photosystems, photolysis, cyclic/non-cyclic photophosphorylation and chloroplast compartments.

Follow RuBP, GP and TP through carbon fixation, reduction and regeneration.

Light reactions supply ATP and NADPH; carbon reactions return ADP, phosphate and oxidized NADP.

Balance the net equation without misidentifying the oxygen source

1. **Simplified net model.** Six carbon dioxide + six water → one glucose equivalent + six oxygen, using light energy.
2. **Origins.** Carbon comes from carbon dioxide; released oxygen comes from water. The net equation does not map every atom movement.
3. **Organisms.** Plants, algae and cyanobacteria perform oxygenic photosynthesis. Cyanobacteria have photosynthetic membranes without chloroplasts.

Light supplies energy rather than carbon atoms

Organic compounds connect photosynthesis to respiration and growth

Chlorophyll absorbs light; it is not consumed as a reactant in the simplified net equation.

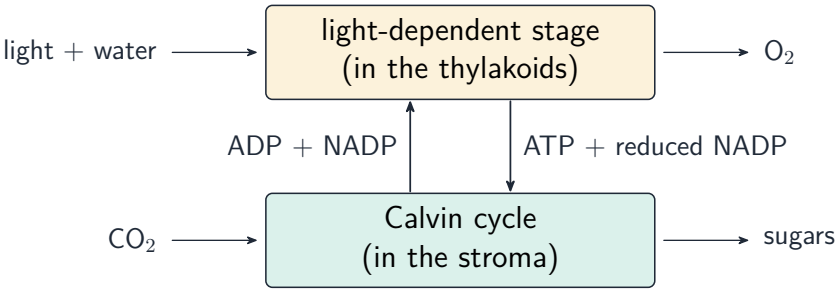
Some other photosynthetic bacteria use different electron donors and do not release oxygen.

Plants also respire in light. Net gas exchange combines photosynthesis with concurrent respiratory uptake/release.

Estimate gross production from net exchange with an assumption

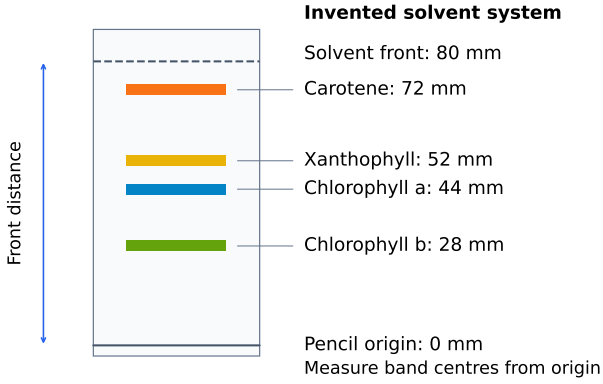
1. **Invented rates.** Net oxygen release 12 units/hour; respiratory uptake estimate three units/hour.
2. **Calculate.** Gross production estimate $= 12 + 3 = 15$ units/hour.
3. **Limit.** This assumes the respiration estimate applies in light. Darkness can change physiology, so a dark rate is not an assumption-free correction.

The two stages of photosynthesis



ADP and NADP return to the thylakoids

Identify the origin, band centres and solvent front



Measure each band centre and the solvent front from the same pencil origin.

A useful chromatogram starts with a controlled separation

Migration depends on both mobile and stationary phases

Chlorophyll a, chlorophyll b and carotenoids differ in their interactions with the solvent and stationary phase.

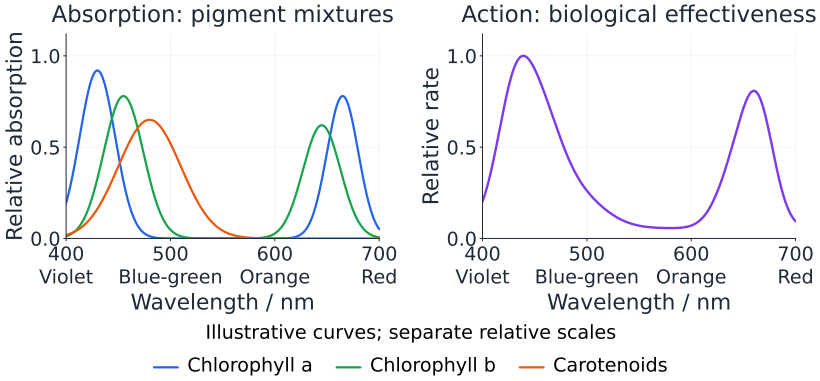
Keep the concentrated starting spot above the solvent reservoir; cover the chamber and use approved solvents safely.

Mark the front promptly. Overlapping/streaked bands make a centre uncertain; changing solvent can change migration order.

A ratio is not a wavelength or a universal pigment identity

1. **Invented standard separation.** Front 80 mm; bands 72, 52, 44 and 28 mm. Ratios 0.90, 0.65, 0.55 and 0.35.
2. **Unknown.** $56/80 = 0.70$; it does not exactly match those four standards.
3. **Identification.** Compare colour and ratio under the same conditions. Co-migration means a match supports identity without proving it uniquely.

Compare a physical measurement with a biological response



Absorption concerns captured light; action concerns photosynthetic effectiveness.

Pigment structure determines allowed electron excitations

Use wavelengths and colours accurately

Visible wavelengths for this topic are about 400–700 nm: violet/blue is shorter than red.

An absorbed photon excites an electron. Different pigment structures give different absorption patterns.

Chlorophylls absorb strongly in parts of blue and red; carotenoids broaden absorption. Green absorption is weaker, not necessarily zero.

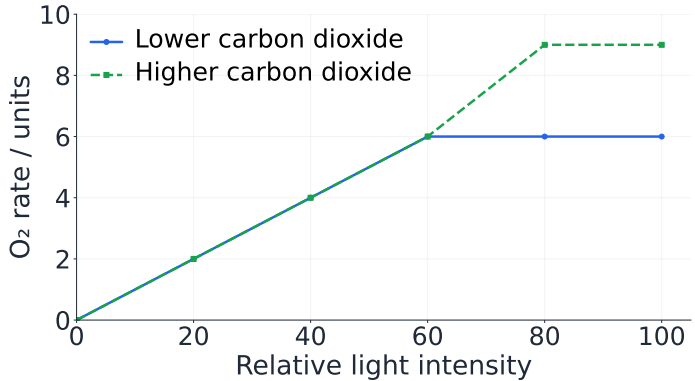
Do not substitute one spectrum for the other

Spectrum	**Measurement and conditions**
Absorption	Absorbed light against wavelength for a pigment or mixture
Action	Photosynthetic rate/effectiveness against wavelength, e.g. oxygen release
Fair comparison	Comparable photon supply, temperature, carbon dioxide and samples
Why curves differ	Accessory pigments, excitation transfer, tissue optics and other rate limits

Build an action spectrum from supplied gas data

1. **Invented three-wavelength test.** 450, 550 and 650 nm; 4.8, 1.2 and 3.6 cubic centimetres oxygen over 2.0 minutes each.
2. **Rates.** 2.4, 0.60 and 1.8 cubic centimetres/minute. Plot each at its wavelength; three points do not locate an exact peak.
3. **Conditions.** Comparable photon supply, temperature, carbon dioxide and samples; specify net exchange or the assumption used to estimate gross production.

A second treatment tests one explanation for a plateau



Higher carbon dioxide raises the invented high-light plateau at fixed temperature.

A plateau describes a response before it explains a cause

1. **Original comparison.** At fixed temperature/carbon dioxide, rate rises from two to four as light rises 20 to 40; it stays six as light rises 80 to 100.
2. **Inference.** Added light has little effect over that plateau interval. The graph alone cannot identify the next constraint.
3. **Test.** Raise carbon dioxide at the same high light with other conditions controlled; replicate and compare variation.

Quantify a treatment response without extrapolating indefinitely

1. **Invented result.** At high light, carbon-dioxide enrichment raises rate from six to nine units/minute.
2. **Percentage.** $(9 - 6)/6 \times 100 = 50\%$ increase.
3. **Interpretation.** Supports carbon-dioxide limitation there. Another constraint can limit later; low-light plants may respond differently.

Temperature changes reaction conditions rather than supplying carbon

Enzymes, membranes and water status all matter

Warming below a suitable range can speed enzyme-controlled steps; excessive heat can impair enzymes and membranes.

Carbon dioxide is a substrate; extra supply helps only where its availability constrains carbon processing.

There is no single universal temperature optimum or a limiting factor fixed for every condition throughout a plant's life.

A gas volume needs time before it becomes a rate

1. **Invented collection.** 7.2 cubic centimetres in 4.0 minutes after acclimation.
2. **Calculate.** $7.2/4.0 = 1.8$ cubic centimetres/minute.
3. **Limits.** Bubble sizes vary; gas dissolves and collection can leak. Establish gas identity before calling the entire collected volume oxygen.

Moving a lamp changes more than one possible influence

Problem	Control or qualification
Heating	Measure temperature; use a controlled bath or suitable low-heat light
Light calibration	Measure at the sample; distance is not automatically intensity
Carbon supply	Control solution chemistry; bicarbonate can change pH too
Biological variation	Comparable independent shoots, acclimation, replication and treatment order

Repeat readings and independent plants answer different questions

An apparatus reading does not automatically become a biological replicate

Repeat readings on one shoot estimate repeatability. Separate comparable shoots help estimate between-shoot variation.

Control species, size/mass/area basis, health, temperature, carbon supply, measurement time and acclimation.

A nearby extended lamp need not follow an exact inverse-square calibration; leaks and temperature/pressure changes can distort gas volumes.

Compare environmental control with field realism

Design	Strength and limitation
Greenhouse	Can control temperature, water and carbon dioxide; enclosure changes microclimate
FACE	Outdoor enrichment reduces enclosure effects; wind/weather make concentration control harder
Replication	Use independent treatment/control rings, monitor concentrations and compare management
Inference	Many leaves in one ring are not many independent enrichment treatments

Yield is a longer-term outcome than a leaf gas rate

1. **Invented rings.** Control dry harvested yield 400 g/square metre; enriched 460 g/square metre.
2. **Increase.** $(460 - 400)/400 \times 100 = 15\%$.
3. **Limit.** Evaluate independent-ring variation. Water, nitrogen, temperature, respiration, allocation and development can prevent a proportional yield response.

Antenna energy transfer and reaction-centre electron transfer differ

A pigment array combines broad capture with organized charge separation

Antenna pigments absorb different wavelengths and transfer excitation energy toward a reaction centre.

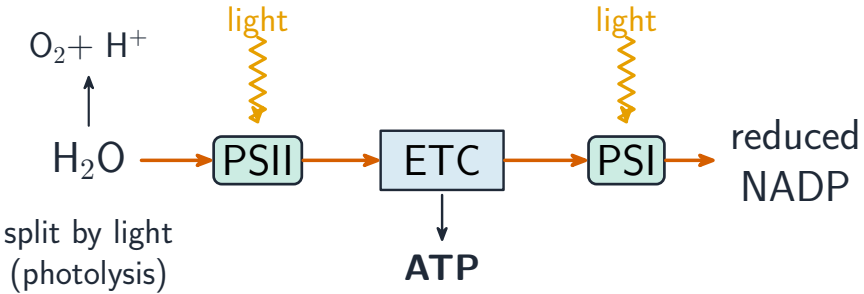
An excited reaction-centre electron can transfer to an acceptor; replacement electrons are required to continue.

An isolated pigment can absorb light, but does not alone perform the coordinated membrane pathway.

Replace lost electrons by oxidizing water at photosystem II

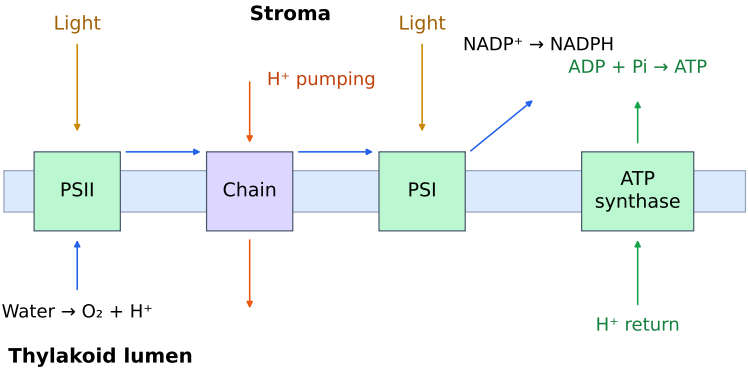
1. **Route order.** Non-cyclic flow passes photosystem II before photosystem I; numbering reflects discovery history.
2. **Water splitting.** Two water $\rightarrow$ one oxygen $+$ four protons $+$ four electrons; protons contribute to the lumen gradient.
3. **Distinction.** Oxygen is a by-product here. It is not the terminal electron acceptor as it is in aerobic respiratory electron transport.

The light-dependent reactions



Photosystem I reduces NADP

Follow electron flow separately from proton return



ATP-synthase proton return runs from lumen to stroma, opposite to pumping.

Non-cyclic flow transfers electrons from water toward NADP

Two light excitations help support the electron-transfer sequence

Electrons pass PSII $\rightarrow$ carriers $\rightarrow$ PSI. Further light absorption at PSI re-excites electrons.

NADP accepts two electrons and a proton to form NADPH on the stromal side. Reduced NADP differs from reduced NAD.

Electron transfer supports proton movement stroma $\rightarrow$ lumen. The membrane restricts uncontrolled proton return.

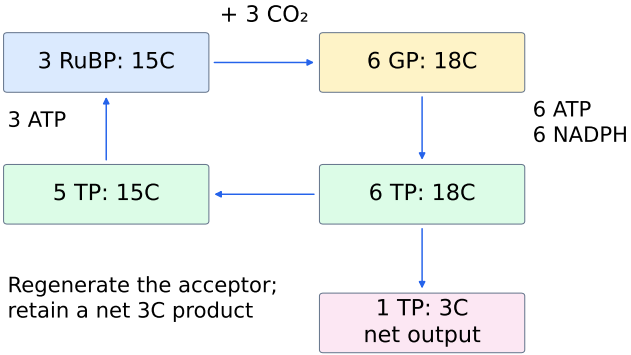
Chemiosmosis links a membrane gradient to stromal ATP

1. **Compartments.** Water oxidation contributes lumen protons; pumping further builds an electrochemical difference.
2. **Return.** Lumen $\rightarrow$ stroma through ATP synthase supports ADP + inorganic phosphate $\rightarrow$ ATP on the stromal side.
3. **Structure.** Extensive thylakoid membrane supports photosystems/carriers; a small lumen supports gradient formation. The envelope is a different membrane system.

Compare cyclic and non-cyclic photophosphorylation

Route	**Net outputs and electron fate**
Non-cyclic	PSII and PSI; water supplies electrons ending in NADPH; ATP and oxygen also produced
Cyclic	PSI electrons return through carriers; supports ATP formation
Cyclic limits	No net NADPH, water splitting or oxygen release in that route
Role	Adjusts ATP supply relative to reducing power; does not replace carbon-dioxide supply

Count recycled carbon separately from net input and output



Regenerate the 15C acceptor pool; retain one net 3C TP.

Fix carbon before reducing GP and regenerating RuBP

1. **Carboxylation.** Rubisco catalyses 5C RuBP + carbon dioxide $\rightarrow$ unstable 6C product $\rightarrow$ two 3C GP.
2. **Reduction.** ATP and NADPH support GP $\rightarrow$ TP; oxidized NADP is regenerated.
3. **Regeneration.** Most TP plus further ATP regenerates RuBP. Some TP leaves for synthesis; the acceptor is not consumed permanently.

Account per three carbon dioxide rather than per imagined glucose turn

1. **Carbon.** Three RuBP: 15C; + three carbon dioxide → six GP: 18C → six TP: 18C.
2. **Partition.** Five TP: 15C → three RuBP; one TP: 3C net output. Five-sixths of TP regenerates acceptor.
3. **Cost.** Six ATP and six NADPH for reduction, plus three ATP for regeneration: nine ATP and six NADPH per net TP.

A carbon skeleton still needs other elements and pathways

Net TP can supply diverse organic products

Two net TP provide a six-carbon carbohydrate equivalent; this standard accounting needs six carbon dioxide, 18 ATP and 12 NADPH.

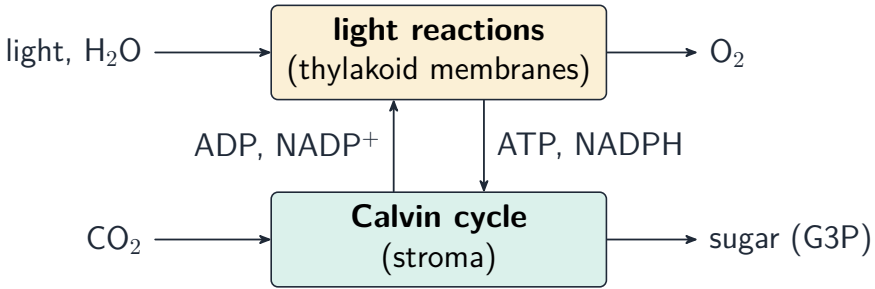
Carbon can enter sugars, starch, cellulose, lipids and amino acids. Amino acids need nitrogen; other products need appropriate minerals.

Rubisco is commonly described as Earth's most abundant enzyme; high stromal concentrations support relatively slow turnover. Enzyme presence cannot overcome all substrate or energy-carrier shortages.

Carbon-dioxide shortage can constrain a light-driven pathway

1. **Interdependence.** Light reactions provide ATP/NADPH; carbon reactions return ADP, phosphate and oxidized NADP.
2. **Low carbon dioxide.** Less carboxylation/downstream processing reduces NADPH use and NADP regeneration; electron-acceptor availability can constrain non-cyclic flow.
3. **Low light.** ATP/NADPH supply declines. Light-independent means no direct photon absorption in those reactions, not indefinite operation without light-reaction products.

The two stages depend on each other



Stop one stage and the other soon stops

Attempt the handout questions before checking

Use measurement, control and scope in each explanation

Calculate chromatographic ratios, gross/net gas estimates and percentage rate/yield changes.

Explain spectra and assess a limiting-factor experiment, including heating and biological replication.

Compare greenhouse and FACE designs; identify an independent experimental treatment unit.

Check common calculations against their stated denominators

1. **Chromatography / gas.** $81/90 = 0.90$; $54/90 = 0.60$; $36/90 = 0.40$. Gross estimate $9 + 2 = 11$ units/hour.
2. **Rates.** $9.0/5.0 = 1.8$ cubic centimetres/minute. Rate $8 \to 10$ is a 25% increase.
3. **Yield.** $500 \to 560$ g/square metre is a 12% increase. Use the original control yield as the percentage denominator.

AHL answers: preserve carbon and compartment direction

1. **Six carbon dioxide.** Six RuBP (30C) $\rightarrow$ twelve GP/TP (36C); ten TP restore six RuBP (30C); two TP (6C) are net output.
2. **Energy/carriers.** 18 ATP and twelve NADPH in the standard ledger. Cyclic PSI flow supplies ATP without net NADPH or oxygen.
3. **Direction.** Non-cyclic electrons: water $\rightarrow$ PSII $\rightarrow$ chain $\rightarrow$ PSI $\rightarrow$ NADP. ATP-synthase protons: lumen $\rightarrow$ stroma.

Check yourself

Name the evidence before stating the conclusion

Water supplies released oxygen; carbon dioxide supplies carbon; photons supply energy.

A pigment ratio is conditional, an absorption spectrum is not a rate curve, and a plateau is not a unique diagnosis.

A higher short-term leaf rate does not guarantee the same whole-season yield increase.