

Photosynthesis

A-Level Biology 9700 · Topic 13 revision notes

Everything from the 4 lessons of this topic on a few pages: the key idea of each lesson, the diagram to remember, the points to learn and the traps examiners set. Read it, cover it, test yourself.

1. Chloroplasts and pigments

2. The light-dependent stage

3. The Calvin cycle

4. Limiting factors and investigations

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1 Chloroplasts and pigments

Syllabus 13.1

Photosynthesis transfers light energy into chemical energy. In the **light-dependent stage**, on the **thylakoid membranes** (stacked into **grana**), light energy is used to make **ATP** and **reduced NADP**. In the **light-independent stage** (the **Calvin cycle**) in the **stroma**, that ATP and reduced NADP are used to turn carbon dioxide into complex organic molecules. Light is absorbed by **chloroplast pigments** in the thylakoids: **chlorophyll a** (the primary pigment) and the **accessory pigments** chlorophyll b, carotene and xanthophyll, which widen the range of wavelengths used. An **absorption spectrum** shows how much light a pigment absorbs at each wavelength; an **action spectrum** shows the rate of photosynthesis at each wavelength. The pigments can be separated by **chromatography** and identified by their **R_f values**.

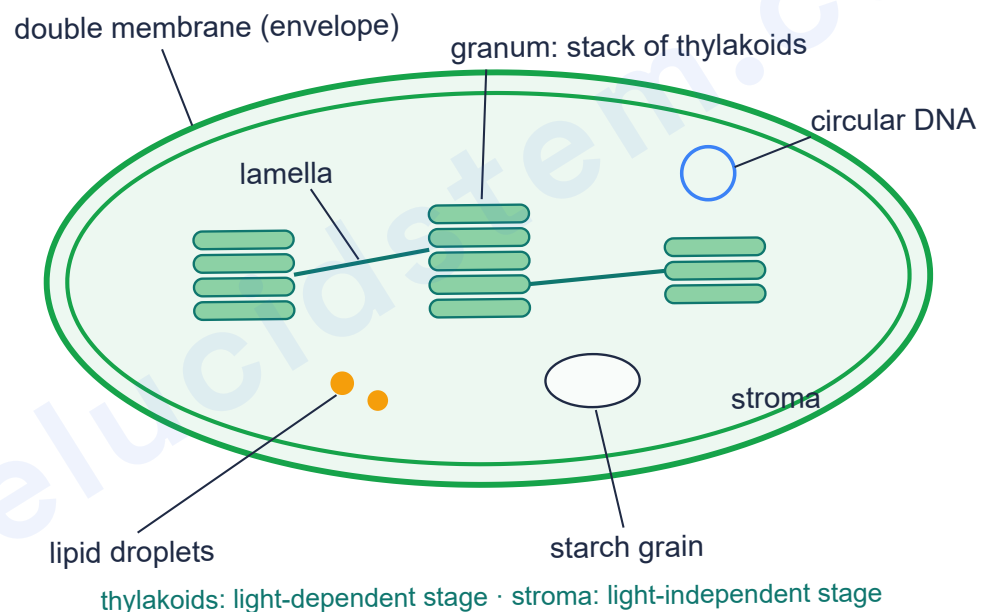


Fig. 1: a chloroplast as seen in an electron micrograph, with grana linked by lamellae, set in the stroma

Sites, spectra, ratios.

- ✓ **Thylakoids (grana):** light-dependent.
Stroma: Calvin cycle.
- ✓ **Absorption spectrum** = absorbance of a pigment; **action spectrum** = rate.
- ✓ **Accessory pigments** widen the range of wavelengths used.
- ✓ $R_f = \text{pigment distance} \div \text{solvent distance, from the origin.}$

Watch out!

Learn the sites exactly: the **thylakoids** (membranes and spaces, in grana) are the site of the light-dependent stage; the **stroma** is the site of the light-independent stage. The light-independent stage is not "the dark reaction": it needs a constant supply of products from the light-dependent stage, so it stops soon after the light goes off.

An R_f value only identifies a pigment if it is compared with known values for the **same solvent and the same paper or plate**. Change the solvent and every R_f changes. Measure both distances from the origin line, not from the bottom of the paper.

2 The light-dependent stage

Syllabus 13.1

The light-dependent stage happens on the **thylakoid membranes** by **photophosphorylation**: making ATP using light energy. Light absorbed by a photosystem causes **photoactivation** of chlorophyll: electrons are excited to a higher energy level and leave it. In **non-cyclic photophosphorylation**, **PSII and PSI** are both involved, the **oxygen-evolving complex** catalyses the **photolysis of water** to replace the electrons lost from PSII, and both **ATP and reduced NADP** are made, with oxygen as a by-product. In **cyclic photophosphorylation** only **PSI** is involved; electrons return to PSI and only **ATP** is made. In both, energetic electrons release energy along the **electron transport chain**; that energy transfers **protons** into the thylakoid space, and the protons return to the stroma by **facilitated diffusion through ATP synthase**, providing the energy for ATP synthesis.

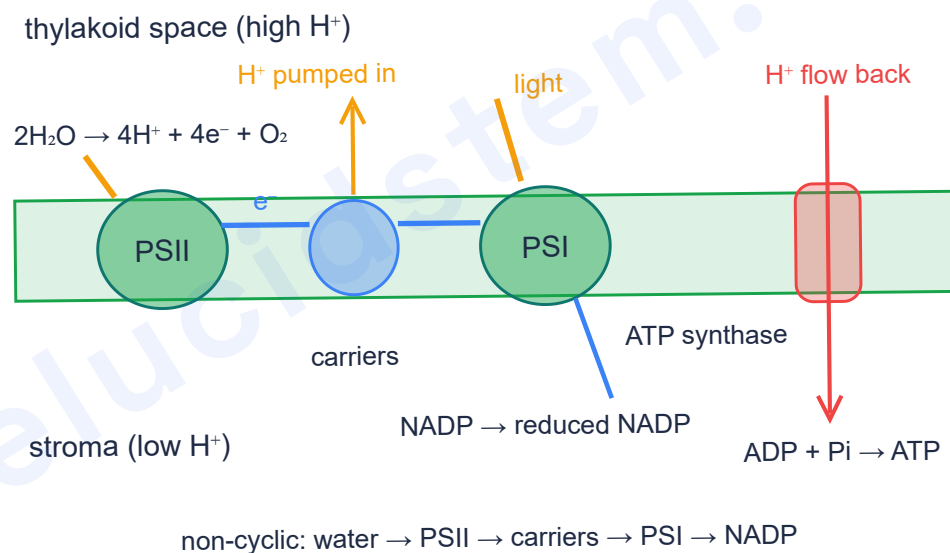


Fig. 1: non-cyclic photophosphorylation on a thylakoid membrane, with proton pumping and ATP synthesis through ATP synthase

Two paths, one gradient.

- ✓ **Non-cyclic:** PSII + PSI, photolysis, ATP + reduced NADP + O₂.
- ✓ **Cyclic:** PSI only, ATP only.
- ✓ **Oxygen** comes from water, split by the oxygen-evolving complex.
- ✓ **H⁺** pumped into the thylakoid space, back out through ATP synthase.

Watch out!

Oxygen comes from **water**, split by photolysis, not from carbon dioxide. And cyclic photophosphorylation makes **no reduced NADP and no oxygen**: check the counters in the simulator, where only ATP keeps rising.

Protons are pumped **into** the thylakoid space and flow **out** to the stroma through ATP synthase, so ATP is made on the stroma side, where the Calvin cycle needs it. Do not mix this up with the mitochondrion, where protons are pumped into the intermembrane space.

3 The Calvin cycle

Syllabus 13.1

The **Calvin cycle** (light-independent stage) takes place in the **stroma** and uses the **ATP** and **reduced NADP** from the light-dependent stage to make complex organic molecules. It has three main stages. **Fixation:** the enzyme **rubisco** combines carbon dioxide with **ribulose biphosphate** (RuBP, 5C), giving two molecules of **glycerate 3-phosphate** (GP, 3C). **Reduction:** GP is reduced to **triose phosphate** (TP, 3C) in reactions using reduced NADP and ATP. **Regeneration:** most of the TP is used to regenerate RuBP, in reactions that use ATP. The remaining TP is used to make **carbohydrates, lipids and amino acids**, and some GP is used to make **amino acids**.

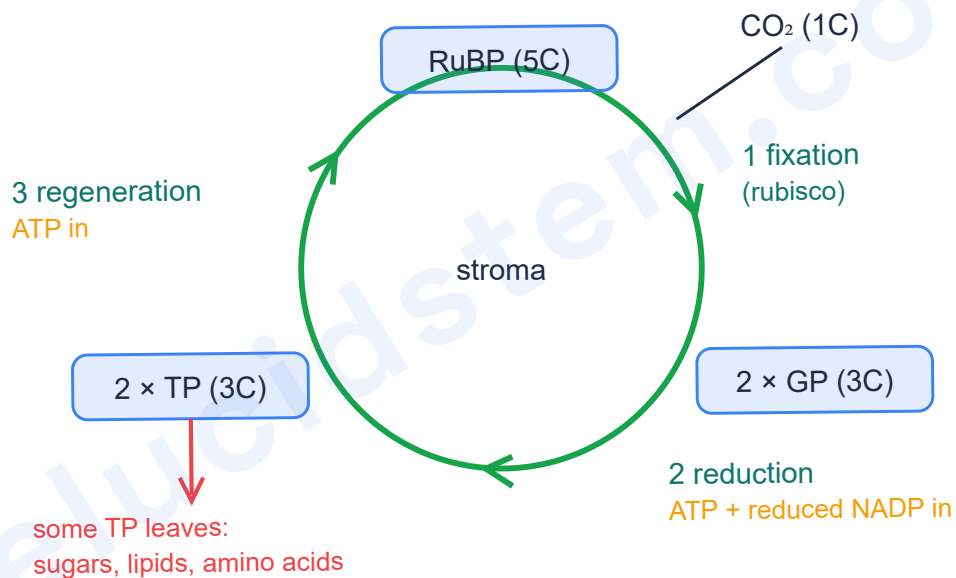


Fig. 1: the three stages of the Calvin cycle in the stroma, shown for one carbon dioxide molecule fixed

5C in, 3C out.

- ✓ **Fixation:** rubisco, $\text{CO}_2 + \text{RuBP (5C)} \rightarrow 2 \text{ GP (3C)}$.
- ✓ **Reduction:** $\text{GP} \rightarrow \text{TP}$ using ATP and reduced NADP.
- ✓ **Regeneration:** $\text{TP} \rightarrow \text{RuBP}$ using ATP.
- ✓ **Light off:** GP up, RuBP down. **CO₂ off:** GP down, RuBP up.

Watch out!

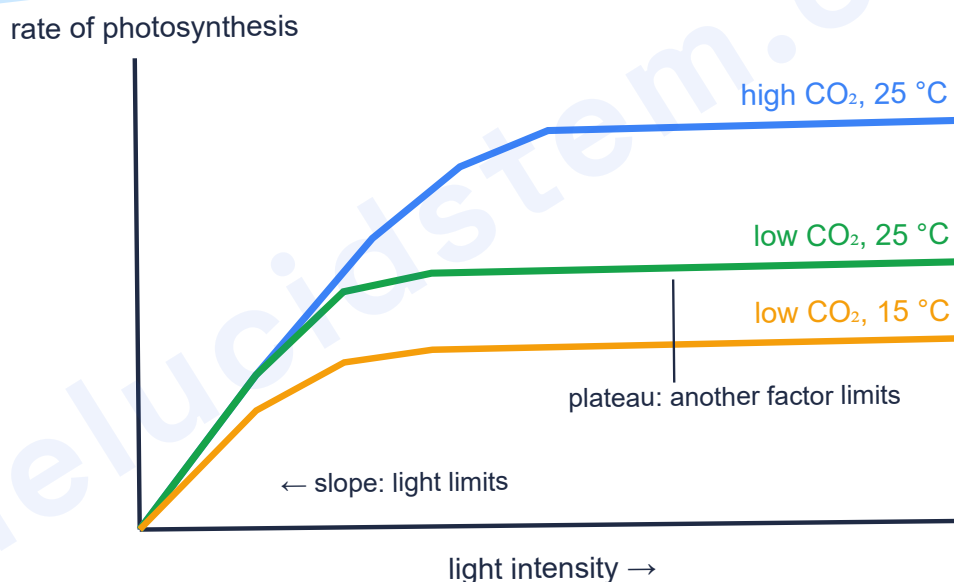
Rubisco fixes carbon dioxide; it does not use ATP. ATP and reduced NADP are used in the **reduction** of GP to TP, and ATP again in **regenerating** RuBP. Also: RuBP is 5C, GP and TP are both 3C.

In data questions about switching the light off, the first change is in the **reduction** step: GP rises because it is still being made from RuBP but can no longer be reduced, and RuBP falls because it is not regenerated.

4 Limiting factors and investigations

Syllabus 13.2

A **limiting factor** is the factor in shortest supply, which limits the rate of a process; increasing it increases the rate. **Light intensity**, **carbon dioxide concentration** and **temperature** are limiting factors of photosynthesis. More light raises the rate by supplying more ATP and reduced NADP from the light-dependent stage; more carbon dioxide raises the rate of fixation by rubisco; temperature affects the enzyme-controlled light-independent stage most, with a rise up to an optimum and a fall as enzymes denature. The rate stops rising when a **different** factor becomes limiting. In a **chloroplast suspension**, electrons from the light-dependent stage reduce a **redox indicator** such as **DCPIP** or **methylene blue**, turning it from blue to colourless, so the time taken measures the rate at different light intensities or wavelengths. In **whole plants**, such as pondweed in hydrogencarbonate solution, the rate is measured as oxygen given off.



on the slope light is limiting; on each plateau CO₂ or temperature is

Fig. 1: rate of photosynthesis against light intensity at two carbon dioxide concentrations and two temperatures

Slope, plateau, control.

- ✓ **On the slope:** the factor on the x-axis is limiting.
- ✓ **On the plateau:** name another factor, with evidence.
- ✓ **DCPIP / methylene blue:** blue to colourless when reduced.
- ✓ **Light intensity** $\propto 1/d^2$; control temperature with a heat shield.

Watch out!

On the plateau, do not say light is limiting. Light is no longer limiting there: increasing it has no effect. Name another factor (carbon dioxide or temperature) and back it up from the graph.

DCPIP is **reduced** when it turns colourless, not oxidised. It accepts the electrons that would otherwise reduce NADP, so its colour change measures the light-dependent stage only, not the whole of photosynthesis.

Moving the lamp closer also heats the water, so temperature becomes a second independent variable. Use a water bath, an LED lamp or a heat shield (a tank of water between lamp and plant) to control it.