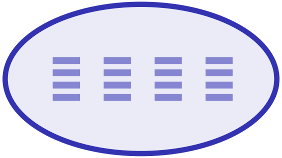
Photosynthesis

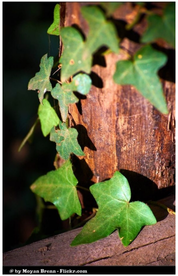
A-Level Biology ▪ Topic 13

A-Level Biology



What we will cover

1. The chloroplast
2. The two stages
3. Pigments & spectra
4. The light-dependent stage
5. The Calvin cycle
6. Limiting factors



leaves are green with chlorophyll

1 Structure and stages

The chloroplast

Double membrane; stacks of **thylakoids** 类囊体 (grana) in a **stroma** 基质 that also holds DNA, ribosomes and starch grains. Light-dependent reactions happen on thylakoid membranes; the Calvin cycle happens in the stroma.

The two stages

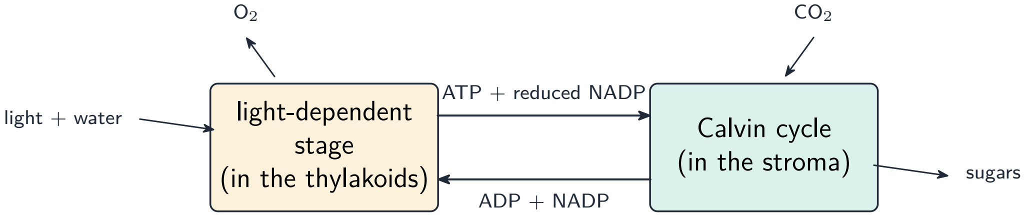
- **light-dependent** 光反应阶段 (thylakoids) – makes ATP & reduced **NADP** NADP
- **Calvin cycle** 卡尔文循环 (stroma) – spends them to fix CO_2 into sugars

Two stages, two places, two products

Light-dependent stage	On the thylakoid membranes: light drives **non-cyclic photophosphorylation** 非环式光合磷酸化, making ATP and reduced NADP.
Photolysis	The **oxygen-evolving complex** 放氧复合物 carries out the **photolysis** 光解 of water – splitting it by light – which replaces the electron and releases **oxygen** 氧气.
Light-independent stage	The **light-independent stage** 暗反应, also called the **Calvin cycle** 卡尔文循环, happens in the stroma and uses those two products to fix CO_2.
Why "light-independent"	It needs no light of its own – but it stops within seconds in the dark, because ATP and reduced NADP stop arriving.

Name the *place* as well as the stage. Thylakoid membrane and stroma are where half the marks live.

The two stages are linked



> The two stages are linked: the first makes the ATP and reduced NADP that the second spends to turn CO into sugars

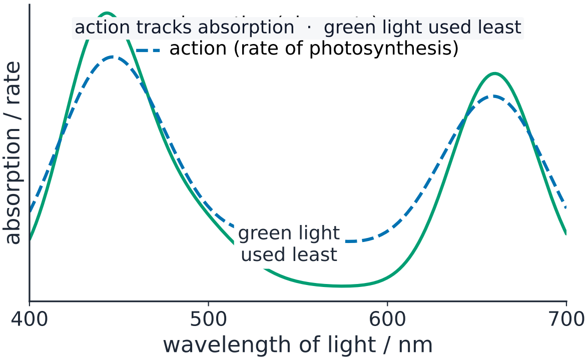
Light-dependent products feed the Calvin cycle

- **Thylakoids**: light splits water → ATP, reduced NADP, and O_2
- **Stroma**: RuBP + CO_2 (**rubisco** 核酮糖二磷酸羧化酶) → GP → TP

> Most TP regenerates RuBP; some makes sugar.

2 Pigments

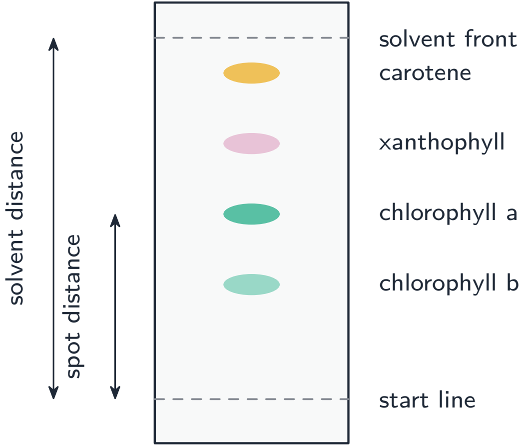
Pigments and spectra



A **pigment** 色素 is a coloured substance that absorbs light. **Chlorophyll** 叶绿素 takes mainly red and blue; **carotene** 胡萝卜素 and **xanthophyll** 叶黄素 absorb other colours and pass the energy on, so the thylakoid traps as much as it can.

> The **absorption spectrum** 吸收光谱 matches the **action spectrum** 作用光谱 – showing the pigments drive photosynthesis.

Chromatography



Chromatography 色谱法 separates the pigments – each travels its own distance up the paper.

$$R_f = \frac{\text{spot distance}}{\text{solvent distance}}$$

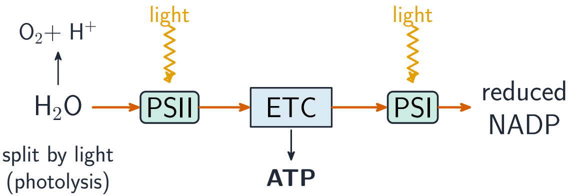
Identifying a pigment

Rf value	Each pigment is identified by its **Rf value** 比移值: the distance the pigment moved divided by the distance the solvent moved.
Why it is constant	Both distances scale together, so Rf does not depend on how long the run was – only on the solvent and the paper.
Absorption spectrum	Different pigments absorb different **wavelengths** 波长, which is why a leaf needs several of them.
Measuring the rate	A redox **indicator** 指示剂 such as DCPIP loses its colour as illuminated chloroplasts work – so you can test different wavelengths directly.

An action spectrum plots the *rate* against wavelength; an absorption spectrum plots what the pigment *absorbs*. Matching the two is the classic exam link.

3 The reactions

The light-dependent stage



Photophosphorylation 光合磷酸化 makes ATP. In the non-cyclic form:

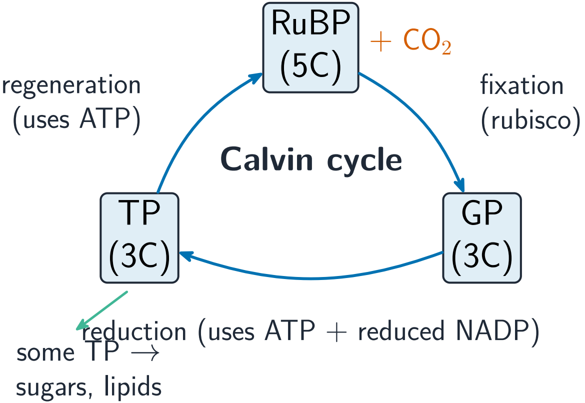
- **photoactivation** 光激活: light boosts chlorophyll's **electrons** 电子 to a higher energy, in both PSI and PSII
- **photolysis** 光解 of water releases **oxygen** 氧气
- electrons flow PSII → PSI
- ATP *and* reduced NADP are made

The light-dependent stage, step by step

1. photolysis	light splits water: $2H_2O \rightarrow 4H^+ + 4e^- + O_2$ – the source of the oxygen released
2. excitation	light raises electrons in chlorophyll to a higher energy level
3. the chain	energetic electrons pass along an **electron transport chain** 电子传递链, releasing energy as they go
4. chemiosmosis	that energy pumps protons into the thylakoid space; they flow back through ATP synthase, making ATP
5. reduction	the electrons finally reduce NADP to NADPH
cyclic photophosphorylation 环式光合磷酸化	electrons return to photosystem I instead – ATP only, no NADPH and no oxygen

Two products go forward to the Calvin cycle: ATP and reduced NADP. Everything in this stage exists to make those two.

The Calvin cycle



- **fixation** 固定 – **rubisco** 核酮糖二磷酸羧化酶 joins CO_2 to RuBP → GP
- **reduction** 还原 – GP → TP using ATP & reduced NADP
- **regeneration** 再生 – TP remakes RuBP

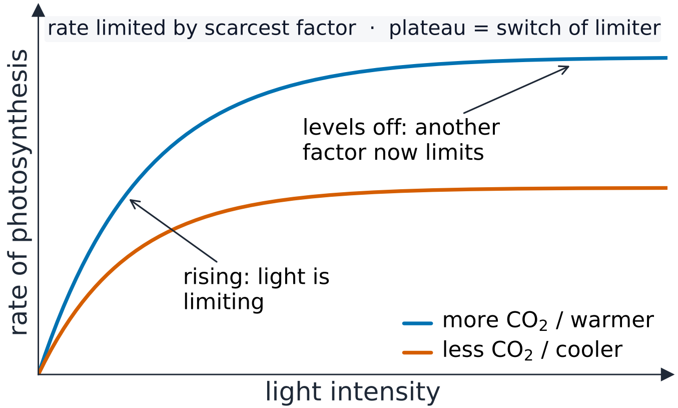
Some TP leaves to make sugars.

Limiting factors

A **limiting factor** 限制因素 is the one in shortest supply.

> While the rate rises, **light** 光照强度 limits it; where it levels off, CO_2 or temperature limits it. (Too hot → enzymes denature.)

Limiting factors, in detail



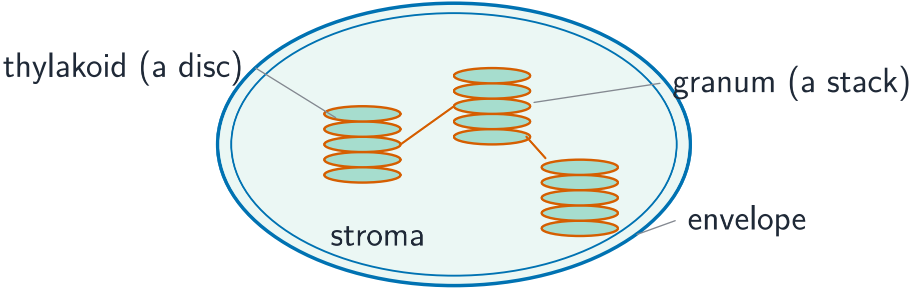
A **limiting factor** 限制因素 is the one in shortest supply.

The Calvin cycle, and what limits the whole process

1. fixation	CO_2 joins RuBP (5C), catalysed by rubisco, giving two molecules of GP (3C)
2. reduction	GP is reduced to TP, using the ATP and reduced NADP from the light stage
3. regeneration	most TP is used to regenerate RuBP; the rest leaves to build **carbohydrates** 碳水化合物, lipids and **amino acids** 氨基酸
light intensity	raises the rate until another factor takes over
CO_2 concentration 浓度	often the limiting factor in the field on a bright day
temperature	speeds it up only to an optimum – too high and the enzymes denature

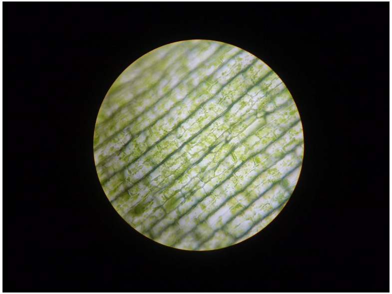
> Measure the light-dependent rate with a redox **indicator** 指示剂 such as DCPIP, or measure oxygen bubbles from an **aquatic plant** 水生植物.

The chloroplast, continued



Thylakoids stack into grana (the first stage happens here); the stroma around them is where the second stage happens

The chloroplast, continued (2)



Chloroplasts (the small green discs) inside the cells of an Elodea (pondweed) leaf, seen under a microscope

Exam tips

- Separate the two stages: **light-dependent** (thylakoid – photolysis, ATP, reduced NADP, O2) and the **Calvin cycle** (stroma – CO2 fixed by rubisco, GP $\rightarrow$ TP).
- Read **limiting-factor** graphs: the plateau is where a different factor (light, CO2 or temperature) limits the rate.
- Interpret **chromatography** with the R_f value to identify pigments.
- Link chloroplast structure to function (thylakoid stacks for the light reactions; stroma for the Calvin cycle).

4 Recap

Worked example – the Calvin cycle disturbed

A plant photosynthesising steadily is suddenly given no CO_2. What happens to GP and RuBP?

- CO_2 joins RuBP (via rubisco) to make GP; no CO_2 $\Rightarrow$ that step stops.
- GP is still being used up, reduced to triose phosphate $\Rightarrow$ GP falls.
- RuBP is still being regenerated from triose phosphate but no longer consumed $\Rightarrow$ RuBP rises.
- Remove the light instead: the opposite – GP rises, RuBP falls.

Track what is made and what is used for each molecule. Cutting CO_2 and cutting light give opposite answers – read which one the question removed.

Topic 13 – key takeaways

1 Chloroplast

grana for stage 1; stroma for stage 2

2 Light stage

photolysis releases O_2; makes ATP & NADPH

3 Calvin cycle

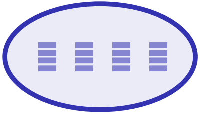
fixation, reduction, regeneration

4 Limiting factors

light, CO_2, temperature

Check yourself

1. Where does the Calvin cycle happen?
2. What gas is released by photolysis of water?
3. Which enzyme fixes carbon dioxide?
4. Name a limiting factor of photosynthesis.



Answers **1.** the stroma **2.** oxygen **3.** rubisco **4.** light / CO_2 / temperature