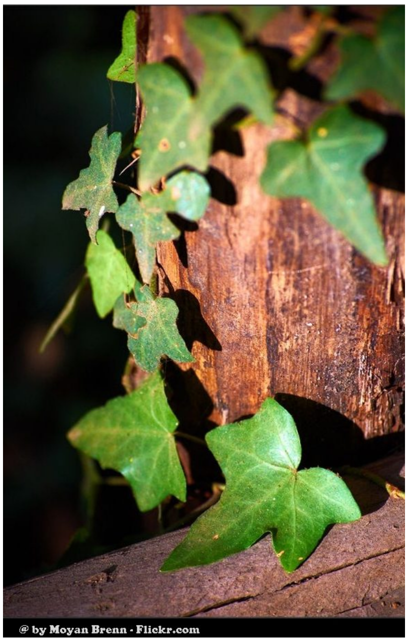
Photosynthesis

A-Level Biology

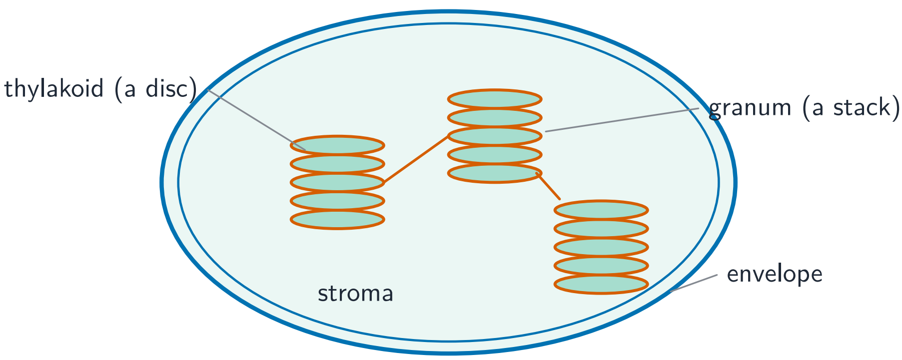
The chloroplast

Photosynthesis 光合作用 happens inside the **chloroplast** 叶绿体. Its structure suits its two stages:

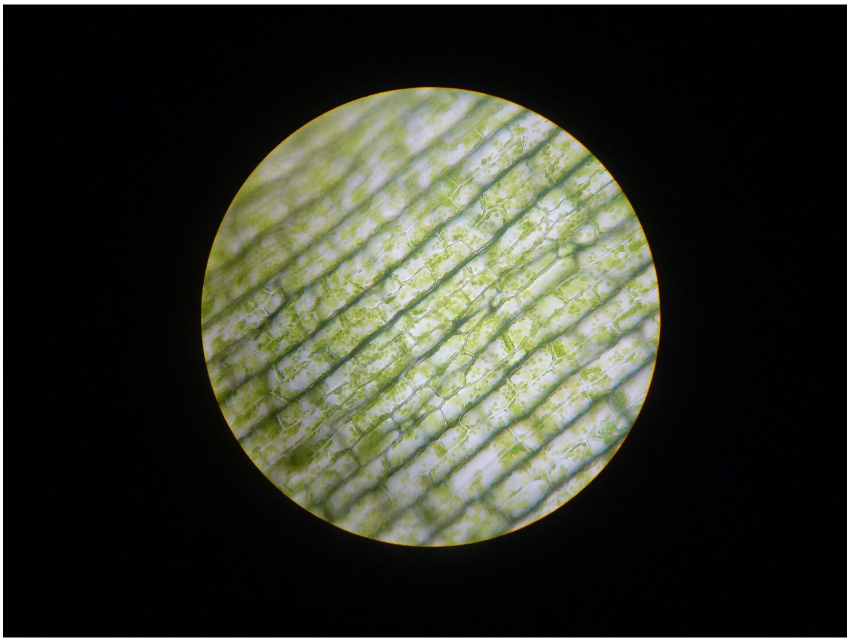
- inside are stacks of flat sacs called **thylakoids** 类囊体. A stack of thylakoids is a **granum** (plural **grana** 基粒). The thylakoid membranes hold the light-trapping pigments and are the site of the first stage.
- the fluid around the thylakoids is the **stroma** 基质, the site of the second stage.



Leaves are green because their chloroplasts are full of the pigment chlorophyll



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

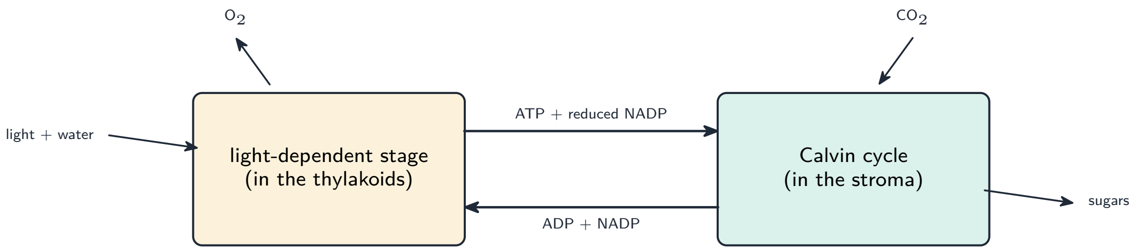


Chloroplasts (the small green discs) inside the cells of an Elodea (pondweed) leaf, seen under a microscope

The two stages of photosynthesis

Photosynthesis has two linked stages:

1. the **light-dependent stage** 光反应阶段 happens in the thylakoids. It uses light energy to make ATP and **reduced** 还原 NADP.
2. the **light-independent stage** 暗反应阶段, also called the **Calvin cycle** 卡尔文循环, happens in the stroma. It uses the ATP and reduced NADP from the first stage to build complex organic molecules from **carbon dioxide** 二氧化碳.



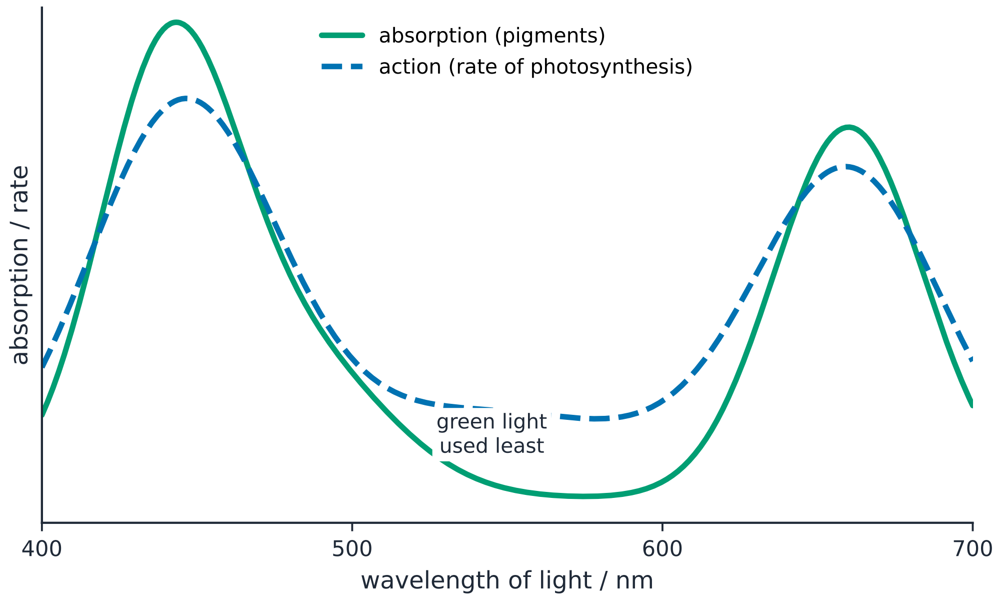
The two stages are linked: the first makes the ATP and reduced NADP that the second spends to turn CO into sugars

Chloroplast pigments

A **pigment** 色素 is a coloured substance that absorbs light. The thylakoids hold several pigments that work together to trap as much light as possible:

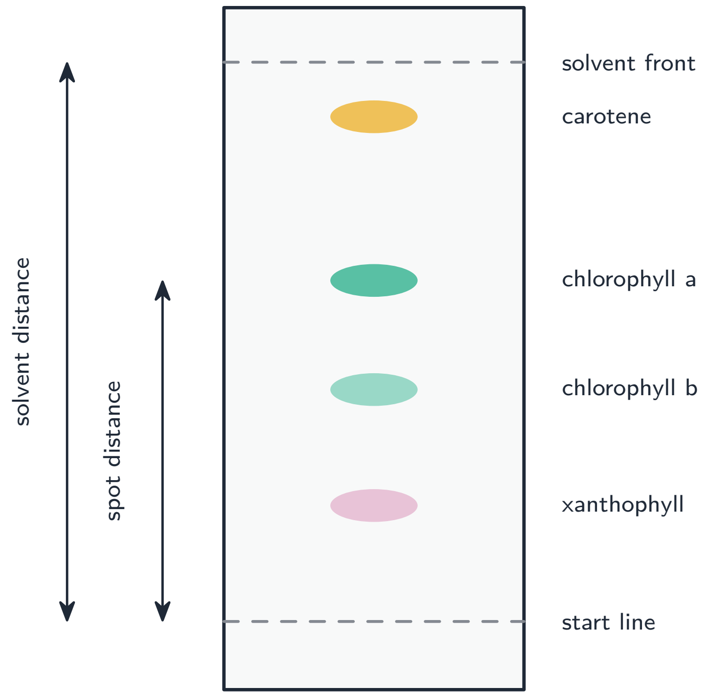
- **chlorophyll** 叶绿素 a and chlorophyll b (which absorb mainly red and blue light),
- **carotene** 胡萝卜素 and **xanthophyll** 叶黄素 (which absorb other colours and pass the energy on).

We study them with two graphs. An **absorption spectrum** 吸收光谱 shows how much light each pigment absorbs at each wavelength. An **action spectrum** 作用光谱 shows how fast photosynthesis goes at each wavelength. The two graphs match closely, which shows the pigments drive photosynthesis.



The absorption spectrum and action spectrum match: blue and red light are used most, green light least

You can separate the pigments by **chromatography** 色谱法: the pigments travel different distances up the paper. Each pigment is identified by its **Rf value** 比移值 (the distance the pigment moved divided by the distance the solvent moved).



Each pigment travels its own distance up the paper; its Rf is the spot distance divided by the solvent distance

The light-dependent stage

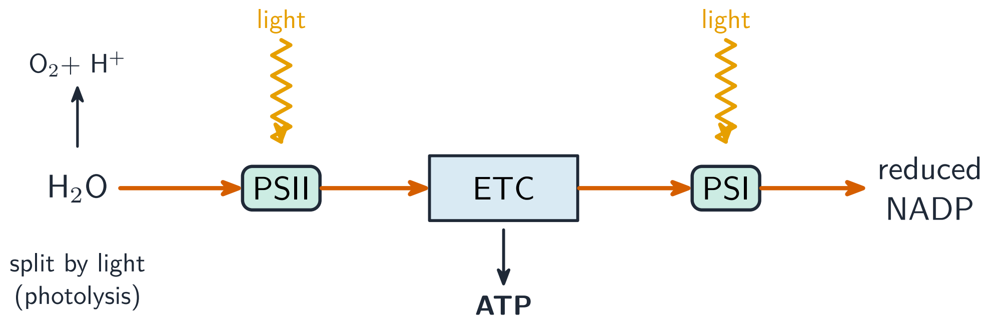
In the thylakoids, light is used to make ATP. This is **photophosphorylation** 光合磷酸化, and it comes in two forms.

In **cyclic photophosphorylation** 循环光合磷酸化:

- only **photosystem** 光系统 I (PSI) is used.
- **photoactivation** 光激活 of chlorophyll occurs (light boosts its **electrons** 电子 to a higher energy).
- only ATP is made.

In **non-cyclic photophosphorylation** 非循环光合磷酸化:

- both photosystem I (PSI) and photosystem II (PSII) are used.
- photoactivation of chlorophyll occurs.
- the **oxygen-evolving complex** 放氧复合体 carries out the **photolysis** 光解 (splitting by light) of water, which releases **oxygen** 氧气.
- both ATP and reduced NADP are made.



In non-cyclic photophosphorylation, photolysis splits water; electrons flow PSII → PSI, making ATP and reduced NADP

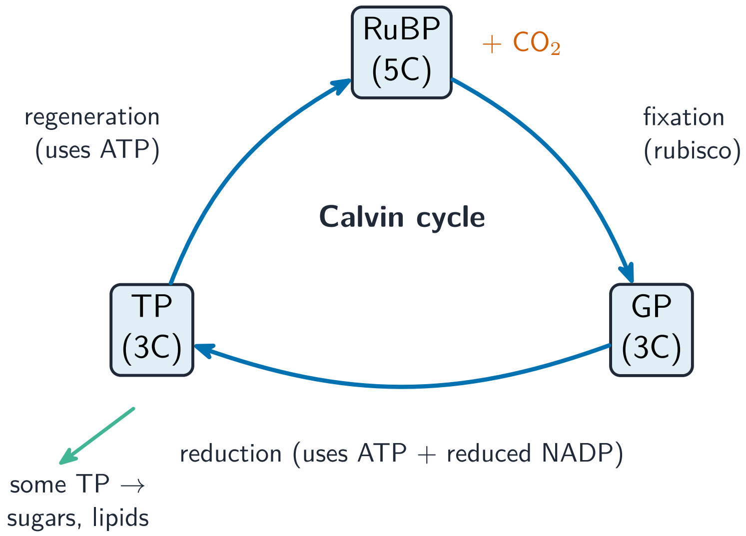
In both forms, energy is released in the same way:

1. energetic electrons pass along an **electron transport chain** 电子传递链, releasing energy as they go.
2. this energy is used to pump **protons** 质子 across the thylakoid membrane.
3. the protons flow back into the stroma through **ATP synthase** 合酶, and this flow provides the energy to make ATP.

The Calvin cycle

The light-independent stage builds sugars in three main steps:

1. **fixation** 固定—the **enzyme** 酶 rubisco joins carbon dioxide to a 5-carbon molecule, RuBP (ribulose bisphosphate). This makes two molecules of a 3-carbon compound, GP (glycerate 3-phosphate).
2. **reduction** —GP is reduced to TP (triose phosphate) using reduced NADP and ATP from the light-dependent stage.
3. **regeneration** —most of the TP is used to **regenerate** 再生 the RuBP (using more ATP), so the cycle can keep running.



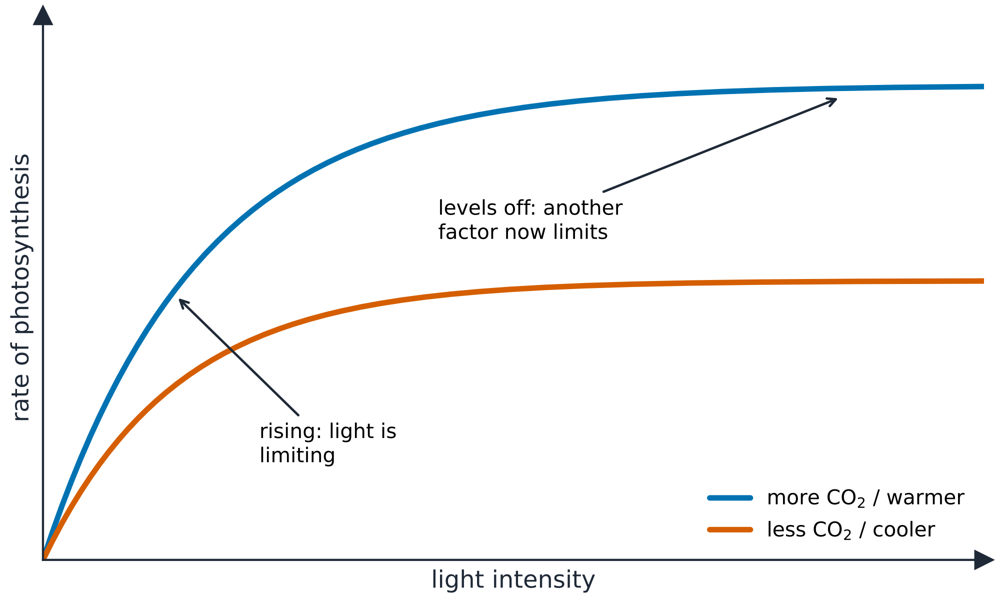
Fixation adds CO to RuBP; reduction makes TP using ATP and reduced NADP; regeneration remakes RuBP; some TP becomes sugars

Some TP leaves the cycle to make useful molecules. GP can be used to make some **amino acids** 氨基酸, and TP can be used to make **carbohydrates** 碳水化合物, **lipids** 脂质 and amino acids.

Limiting factors

A **limiting factor** 限制因素 is the one in shortest supply that holds back the rate of photosynthesis. The three main ones are **light intensity** 光照强度, **carbon dioxide concentration** 浓度, and **temperature** 温度.

- raising light intensity speeds up photosynthesis, until some other factor becomes limiting.
- raising carbon dioxide concentration speeds it up, until some other factor becomes limiting.
- raising temperature speeds it up, but only to an optimum; too high and the enzymes denature.



While the rate rises, light is the limiting factor; where it levels off, another factor (CO or temperature) limits it

You can measure the rate of the light-dependent stage with a redox **indicator** 指示剂 such as DCPIP or methylene blue and a suspension of chloroplasts: the dye loses its colour as the chloroplasts work, and you can test different light intensities or light **wavelengths** 波长. With a whole **aquatic plant** 水生植物 you can count the bubbles of oxygen given off to compare rates under different conditions.

Worked example. A plant photosynthesising steadily is suddenly deprived of carbon dioxide. What happens to the levels of GP and RuBP? Follow the cycle one step at a time. Carbon dioxide is fixed when **RuBP** combines with it, catalysed by rubisco, to make **GP**. Remove the carbon dioxide and that reaction stops, so GP is **no longer being made** - yet GP continues to be **used up**, reduced to TP using ATP and reduced NADP. So **GP falls**. Meanwhile RuBP is still being **regenerated** from TP but is no longer being **consumed**, so **RuBP rises**. The method never changes: find the reaction that stops, then ask of each substance whether it is still being **made** and still being **used**. Removing the **light** instead gives the mirror image: with no ATP or reduced NADP, GP cannot be reduced, so **GP rises and RuBP falls**.

Exam tips

- Separate the two stages: **light-dependent** (thylakoid —photolysis, ATP, reduced NADP, O2) and the **Calvin cycle** (stroma —CO2 fixed by rubisco, GP → 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).