Photosynthesis: how plants turn light into sugar

Plants, algae and some bacteria store the energy of sunlight in the bonds of sugar. Almost every food chain starts here, and so does nearly all of the oxygen in the air.

$$6\ CO_2 + 6\ H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6\ O_2$$

1 Where it happens

Photosynthesis takes place in **chloroplasts**, found mostly in the mesophyll cells of a leaf. Inside a chloroplast, flattened sacs called **thylakoids** are stacked into **grana**. The thylakoid membrane holds the pigment **chlorophyll**. The fluid around the thylakoids is the **stroma**. Carbon dioxide enters the leaf, and oxygen leaves it, through pores called **stomata**.

2 Stage one: the light-dependent reactions

These reactions happen **in the thylakoid membrane** and need light directly.

1. **Photosystem II** absorbs light. Its energised electrons leave, and the photosystem replaces them by splitting water (**photolysis**): $2\ H_2O \rightarrow 4\ H^+ + 4\ e^- + O_2$.
2. The electrons pass down an **electron transport chain**. The energy they lose pumps H^+ ions into the thylakoid space.
3. H^+ ions flow back through the enzyme **ATP synthase**, which makes **ATP**. This is chemiosmosis.
4. **Photosystem I** energises the electrons again, and they reduce $NADP^+$ to **NADPH**.

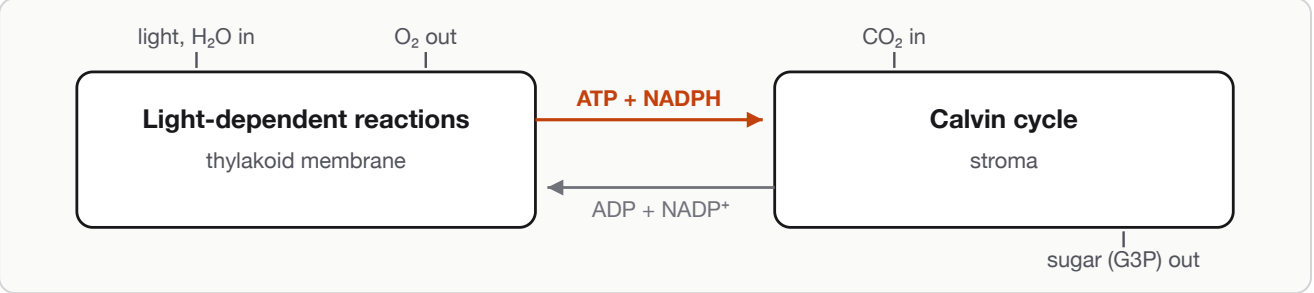


Figure 1. The two stages feed each other: the first makes ATP and NADPH, the second uses them and hands back ADP and $NADP^+$.

> **Remember:** the oxygen a plant releases comes from **water**, not from carbon dioxide. Stage one makes three things: ATP, NADPH and O_2.

3 Stage two: the Calvin cycle

The Calvin cycle happens **in the stroma**. It does not use light directly, but it depends on the ATP and NADPH from stage one, so in a living plant it runs in daylight. It has three phases:

1. **Carbon fixation.** The enzyme **RuBisCO** joins one CO_2 to a five-carbon sugar, RuBP. The six-carbon product splits at once into two molecules of 3-PGA.
2. **Reduction.** ATP and NADPH turn 3-PGA into the three-carbon sugar **G3P**.
3. **Regeneration.** Most of the G3P is rebuilt into RuBP, which costs more ATP, so the cycle can go round again.

Three turns of the cycle fix 3 CO_2 and give a net gain of **one G3P**, at a cost of **9 ATP and 6 NADPH**. One glucose needs two G3P: six turns, 18 ATP and 12 NADPH.

Stage	Where	Needs	Makes
Light-dependent reactions	Thylakoid membrane	Light, H_2O, ADP, $NADP^+$	ATP, NADPH, O_2
Calvin cycle	Stroma	CO_2, ATP, NADPH	G3P (sugar), ADP, $NADP^+$

4 Pigments and the colour of leaves

Chlorophyll a and **chlorophyll b** absorb mostly red and blue-violet light and reflect green, which is why leaves look green. **Carotenoids** absorb blue-green light, pass some of that energy on, and protect chlorophyll from too much light. In autumn chlorophyll breaks down first, and the yellow and orange carotenoids show.

5 What limits the rate

The rate of photosynthesis is set by whichever factor is in shortest supply, the **limiting factor**:

- **Light intensity.** More light raises the rate until another factor runs short; then the curve levels off.
- **Carbon dioxide concentration.** Air holds only about 0.04% CO_2, so this is often the limit on a bright day.
- **Temperature.** The Calvin cycle is run by enzymes. The rate rises with warmth to an optimum, then falls quickly as the enzymes denature. In heat the stomata also close to save water, which cuts off CO_2.

6 C4 and CAM plants

When stomata close, O_2 builds up and RuBisCO starts to fix O_2 instead of CO_2. This wasteful process is **photorespiration**. **C4 plants** such as maize and sugarcane first fix CO_2 into a four-carbon compound and deliver it to RuBisCO in bundle-sheath cells, where the CO_2 level stays high. **CAM plants** such as cacti and pineapple open their stomata at night, store CO_2 as an acid, and use it by day.

> **Three mistakes that cost marks:** “The Calvin cycle happens at night” (it needs the products of the light reactions). “Plants photosynthesise instead of respiring” (they respire all the time). “Chlorophyll absorbs green light” (it reflects it).