Photosynthesis

The overall reaction, ATP, the light-dependent and light-independent reactions, chloroplast structure, pigments and spectra, chromatography of pigments, and Core Practical 10.

The overall reaction

Photosynthesis uses **light energy** to **split water** (photolysis) and stores the hydrogen in the **fuel glucose** by combining it with **carbon dioxide**. Oxygen is released.

$$6CO_2 + 6H_2O \xrightarrow{\text{light, chlorophyll}} C_6H_{12}O_6 + 6O_2$$

The strong bonds in water are broken using light energy, and the energy is stored in the C–H and C–C bonds of glucose.

ATP

ATP (adenosine triphosphate) is the **immediate energy source** in cells. **Hydrolysis** of ATP to ADP and inorganic phosphate (P_i) releases a small, manageable amount of energy for a process, catalysed by **ATPase**. In photosynthesis, **photophosphorylation** adds a phosphate to ADP, using light energy, to make ATP.

Chloroplast structure

- A **double membrane** (envelope).
- **Thylakoids** (flattened sacs) containing the **chlorophyll** pigments, stacked in **grana**, where the **light-dependent** reactions occur. Their large surface area holds many pigment molecules and electron carriers.
- The **stroma**, a fluid containing **enzymes** (including **Rubisco**), **starch grains** and DNA and ribosomes, where the **light-independent** reactions occur.
- **Intergranal lamellae** link the grana.

The light-dependent reactions

These take place in the **thylakoid membranes**.

1. **Light energy** is absorbed by **chlorophyll**, which excites **electrons** to a higher energy level and they leave the chlorophyll.
2. The electrons pass along an **electron transport chain** of carriers. As they pass, energy is released and used to make **ATP** (by **chemiosmosis**, see ATP synthase later). This is **photophosphorylation**.
3. **Photolysis of water**: light splits water into **protons (H^+), electrons and oxygen**: $2H_2O \rightarrow 4H^+ + 4e^- + O_2$. The electrons replace those lost from chlorophyll, and the oxygen is released.

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4. In **non-cyclic photophosphorylation**, the electrons end up reducing **NADP** (with H^+) to **reduced NADP**, and make ATP and oxygen.
5. In **cyclic photophosphorylation**, electrons from the chlorophyll return to the chlorophyll via the carriers. It makes **only ATP**: no NADPH, no oxygen, no photolysis.

> **Products of the light-dependent stage: ATP and reduced NADP (both go on to the Calvin cycle), and oxygen (a by-product).**

The light-independent reactions: the Calvin cycle

These take place in the **stroma**. Carbon dioxide is **reduced** using the ATP and reduced NADP.

1. **Carbon fixation**: CO_2 combines with **ribulose bisphosphate (RuBP, 5C)**, catalysed by **Rubisco**, to form an unstable 6C compound that splits into two molecules of **glycerate 3-phosphate (GP, 3C)**.
2. **Reduction**: GP is reduced to **triose phosphate (GALP, 3C)** using **reduced NADP** (as hydrogen) and **ATP** (as energy).
3. **Regeneration**: most of the GALP is used with ATP to regenerate **RuBP**. One in six GALP molecules is **removed** to make carbohydrates.

The simple sugars made are used for **respiration**, and to synthesise **polysaccharides** (starch and cellulose), **amino acids** (with nitrate), **proteins**, **lipids** (glycerol and fatty acids) and **nucleic acids**.

> **NOTE**
>
> Remember that the light-independent reaction depends on the light-dependent one for ATP and reduced NADP. If light stops, GP builds up and RuBP falls, because GP is not reduced and RuBP is not regenerated.

Pigments and spectra

- **Chlorophyll a and b**, and **carotenoids**, are **photosynthetic pigments**. They absorb different wavelengths and pass the energy to the chlorophyll a in the reaction centre.
- The **absorption spectrum** is a graph of the **amount of light absorbed** at each wavelength by a pigment. Chlorophyll absorbs mostly **red and blue** light and reflects green.
- The **action spectrum** is a graph of the **rate of photosynthesis** at each wavelength. Its shape is similar to the absorption spectrum of all the pigments combined.

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Separating pigments by chromatography

1. Put a **spot** of pigment extract (from ground leaf in propanone) on a **pencil line** near the bottom of a chromatography paper or TLC plate.
2. Stand it in a **solvent** (e.g. propanone and petroleum ether), below the line.
3. The pigments move at different rates and separate, depending on their **solubility** in the solvent and **attraction to the paper**.

$$R_f = \frac{\text{distance moved by the pigment}}{\text{distance moved by the solvent front}}$$

Each pigment has a characteristic R_f value, so it can be identified. Carotene travels furthest and chlorophyll b the least.

Core Practical 10: factors affecting the rate

Use an **aquatic plant** (e.g. *Elodea* or *Cabomba*) and measure the rate of **oxygen production**, by counting **bubbles** or collecting the gas in a **gas syringe**, in a set time.

Factor	How to vary	Control
Light intensity	Move the lamp (intensity is proportional to $1/d^2$)	Temperature (use a **heat shield** or water bath), CO_2
Wavelength	Coloured filters	Intensity, temperature
Temperature	Water bath	Light intensity, CO_2
CO_2 **availability**	Different concentrations of sodium hydrogencarbonate	Light and temperature

Interpretation: rate increases with the factor until another becomes **limiting**. Too high a temperature **denatures** enzymes. Repeat and calculate a mean rate.

> **TRY IT**
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> Explain why the rate of photosynthesis levels off at high light intensity.

Another factor (carbon dioxide concentration or temperature) becomes **limiting**, or the light-independent reaction cannot keep up, because the enzymes (including Rubisco) are working at their maximum rate.

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