

Photosynthesis

Revision notes · IB Biology C1.3: energy transformation, pigments, chromatography, absorption and action spectra, limiting factors and CO₂ enrichment.

For IB Diploma Biology SL undefined. **HL only** is additional higher level content, for HL students only.

Photosynthesis Spec C1.3

Photosynthesis: energy, carbon dioxide, water and oxygen Spec C1.3.1, C1.3.2, C1.3.3

Photosynthesis involves the **transformation of light energy to chemical energy**. Light energy absorbed by pigments is used to make carbon compounds, and the energy is then held in the chemical bonds of those compounds. This energy transformation supplies most of the chemical energy needed for life processes in ecosystems: producers use it directly, and consumers and decomposers obtain it by feeding.

Carbon dioxide, water and glucose

Carbon dioxide is converted to glucose using **hydrogen obtained by splitting water**. Carbon dioxide provides the carbon and oxygen atoms of glucose, but glucose also contains hydrogen, which must come from somewhere: it comes from water molecules, split using energy from light.



Oxygen as a by-product

When water is split, the hydrogen is used and the oxygen is released as a **by-product**. So **the oxygen produced by photosynthesis comes from the splitting of water**, not from carbon dioxide. Oxygen-producing photosynthesis happens in **plants, algae and cyanobacteria**.

Common mistake: Do not write that the oxygen released comes from carbon dioxide. It comes from water; the oxygen atoms of CO₂ end up in glucose and water.

Exam tip: Linking question: the consequences of photosynthesis for ecosystems include supplying chemical energy to food chains and removing carbon dioxide from the atmosphere.

Separating photosynthetic pigments by chromatography Spec C1.3.4

Leaves contain several photosynthetic pigments. They can be separated by **chromatography**, using **paper** or a **thin-layer chromatography (TLC)** plate. Each pigment travels a different distance because it differs in how soluble it is in the solvent and how strongly it is attracted to the stationary phase.

1. Grind leaf tissue with a little sand and propanone (or another suitable solvent) to extract the pigments.
2. Draw a pencil origin line about 1 cm from the bottom of the paper or plate.
3. Apply a small, concentrated spot of extract to the origin, letting it dry between applications.
4. Stand the paper or plate in a small depth of running solvent, below the origin, in a covered container.
5. Remove it when the solvent is near the top and immediately mark the solvent front with pencil.
6. Mark the centre of each pigment spot, measure distances from the origin and calculate R_f values.

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

R_f values are always between 0 and 1 and have no units. Pigments are identified by their **colour** and by comparing their **R_f values** with reference values for the same solvent and stationary phase.

Common photosynthetic pigments and their colours

Pigment	Colour on the chromatogram
Carotene	Orange-yellow (usually travels furthest)
Xanthophylls	Yellow
Chlorophyll a	Blue-green
Chlorophyll b	Yellow-green

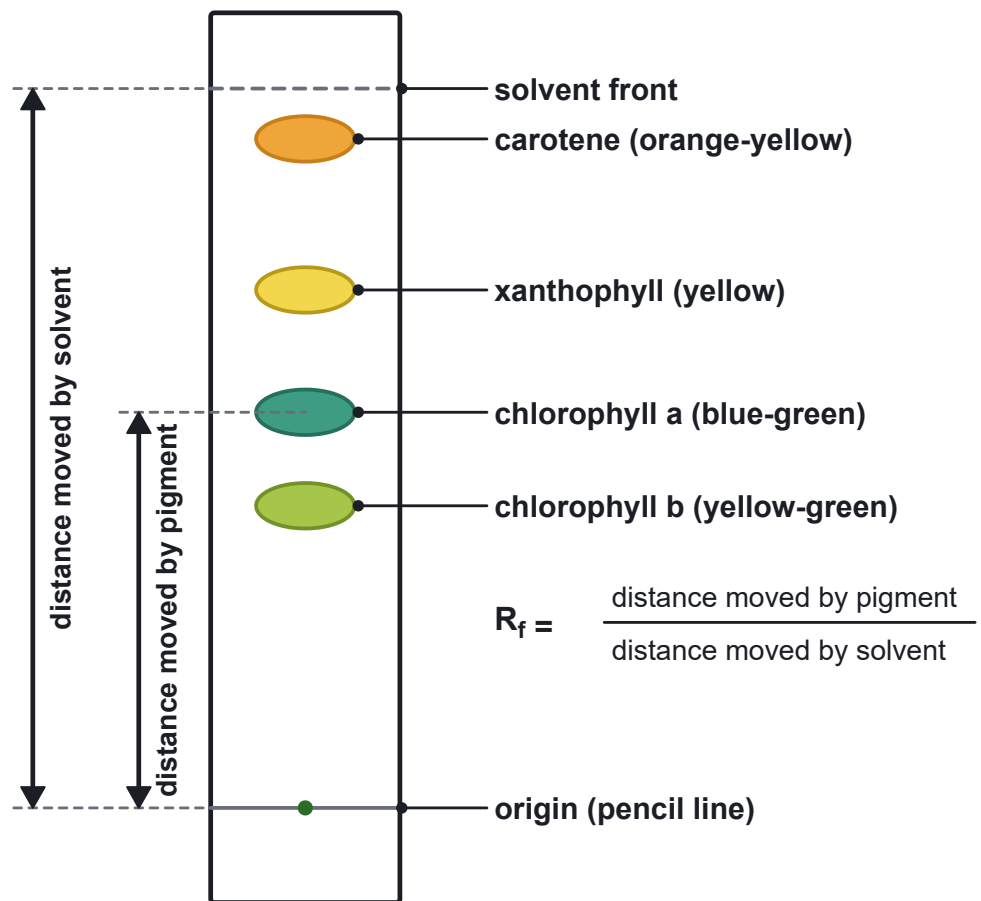
Calculating an R_f value

On a chromatogram the solvent front moved 8.0 cm from the origin. A blue-green spot moved 4.4 cm. Calculate its R_f value.

1. $R_f = \text{distance moved by pigment} \div \text{distance moved by solvent front}.$
2. $R_f = 4.4 \div 8.0 = 0.55.$

Answer: $R_f = 0.55$ (no units). With its blue-green colour this is likely chlorophyll a; confirm with reference values for the same method.

Practical skill: Use a pencil for the origin (ink would separate too), keep the origin above the solvent, and measure to the centre of each spot. R_f values depend on the solvent and medium, so only compare with references from the same method.



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A typical chromatogram of leaf pigments (illustrative positions; order and R_f values depend on the solvent and medium). $R_f = \frac{\text{pigment distance}}{\text{solvent distance}}$.

Absorption of light, absorption spectra and action spectra Spec C1.3.5, C1.3.6

Absorption of specific wavelengths

When a pigment molecule absorbs light, the energy **excites an electron** within the molecule, raising it to a higher energy level. This is the first step in transforming light energy to chemical energy, because the excited electron can be passed on to other molecules.

Only some wavelengths are absorbed. Electrons in a pigment can only occupy certain energy levels, so only photons whose energy matches the gap between levels can be absorbed. Other wavelengths are reflected or transmitted. **Chlorophyll** absorbs red and blue light most strongly and reflects green light, which is why leaves look green. Accessory pigments such as carotenoids absorb other wavelengths, mainly in the blue-green region.

Absorption spectra and action spectra

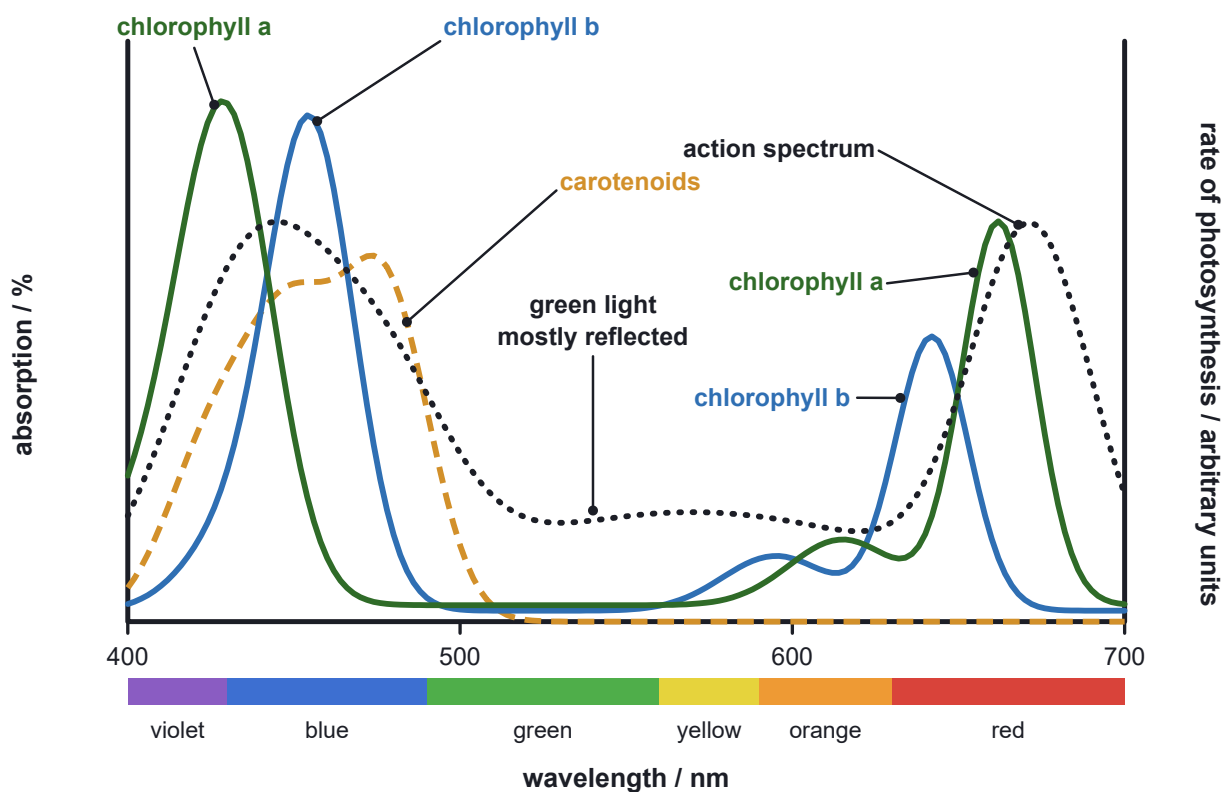
Absorption spectrum	A graph showing the percentage of light absorbed by a pigment (or pigments) at each wavelength.
Action spectrum	A graph showing the rate of photosynthesis at each wavelength of light.

Both graphs have **wavelength** (in nm, from about 400 to 700 nm) on the horizontal axis, which should also show the **colours** of light: violet and blue at the short-wavelength end, then green, yellow, orange and red.

Similarities and differences of absorption and action spectra

	Absorption spectrum	Action spectrum
Vertical axis	% of light absorbed	Rate of photosynthesis
Peaks	Blue and red for chlorophyll	Also blue and red
Green region	Low absorption by chlorophyll	Rate low but not zero, because accessory pigments absorb some light and some green light is absorbed as it passes through the leaf
How obtained	Shine each wavelength through a pigment extract and measure absorbance	Measure rate of oxygen production or carbon dioxide consumption under each wavelength

The **similar shape** of the two graphs is evidence that the light absorbed by these pigments is the light used in photosynthesis.



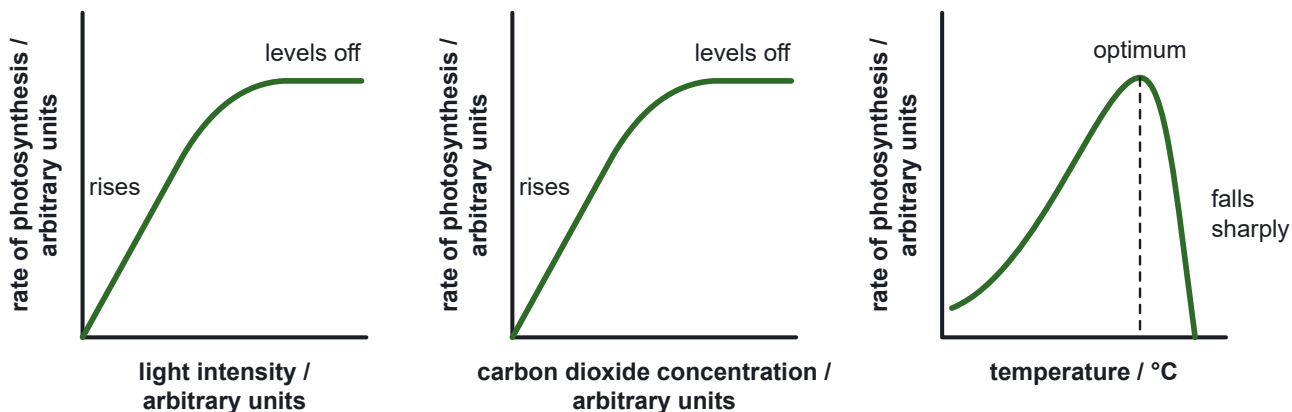
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Illustrative curves: the action spectrum **matches the absorption spectra**, with peaks in blue and red light; green light is mostly reflected.

Maths skill: To make an action spectrum, calculate the rate at each wavelength (for example volume of oxygen $\div$ time, or CO_2 uptake $\div$ time), then plot rate against wavelength with points joined by a smooth curve or straight lines.

Investigating limiting factors on photosynthesis Spec C1.3.7

The rate of photosynthesis depends on several factors. At any moment, the **limiting factor** is the one that is furthest from its optimum: increasing it raises the rate, while increasing the others does not.



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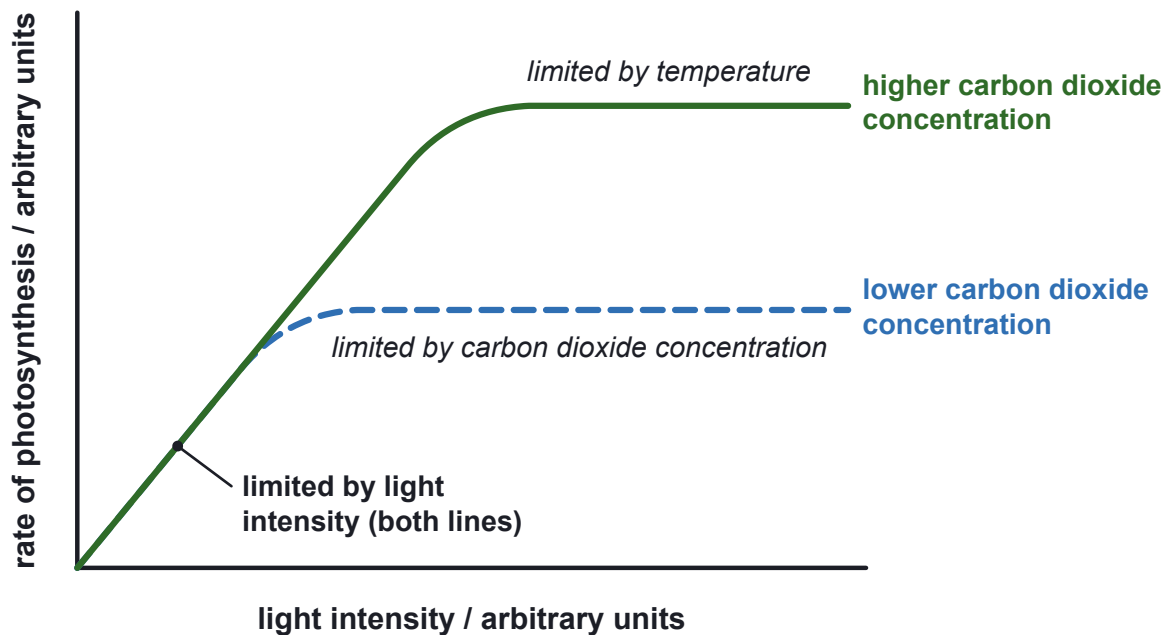
Light intensity and carbon dioxide concentration: the rate **rises, then levels off** when another factor limits. Temperature: the rate rises to an optimum, then falls as enzymes denature.

Techniques for varying each factor

How to vary each limiting factor		
Independent variable	How to vary it	Notes
Light intensity	Change the distance of a lamp from the plant, or use filters or a dimmable LED	Light intensity falls with distance (roughly proportional to $1 \div \text{distance}^2$); use an LED or a heat shield so temperature does not change
Carbon dioxide concentration	Use different concentrations of sodium hydrogencarbonate solution around aquatic plants or leaf discs	Hydrogencarbonate releases CO_2 in water
Temperature	Place the plant in water baths at different temperatures	Allow time to equilibrate; check with a thermometer

Measuring the rate

- Count bubbles or collect the volume of oxygen released by an aquatic plant such as *Elodea* or *Cabomba* per minute.
- Time how long leaf discs (with air removed so they sink) take to float as oxygen builds up.
- Measure carbon dioxide uptake with a sensor and data logger, or by the colour change of a hydrogencarbonate indicator.



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Where each line levels off, light is no longer limiting: the **factor in shortest supply** sets the plateau.

Practical skill: Identify the independent variable (the factor you change) and the dependent variable (the rate, for example oxygen per minute). Keep the other two factors constant and repeat each condition.

Exam tip: A hypothesis is a provisional explanation that needs repeated testing. You can suggest one from theory before the experiment (for example, 'rate rises with light intensity because more light energy is absorbed by chlorophyll') or from results after it.

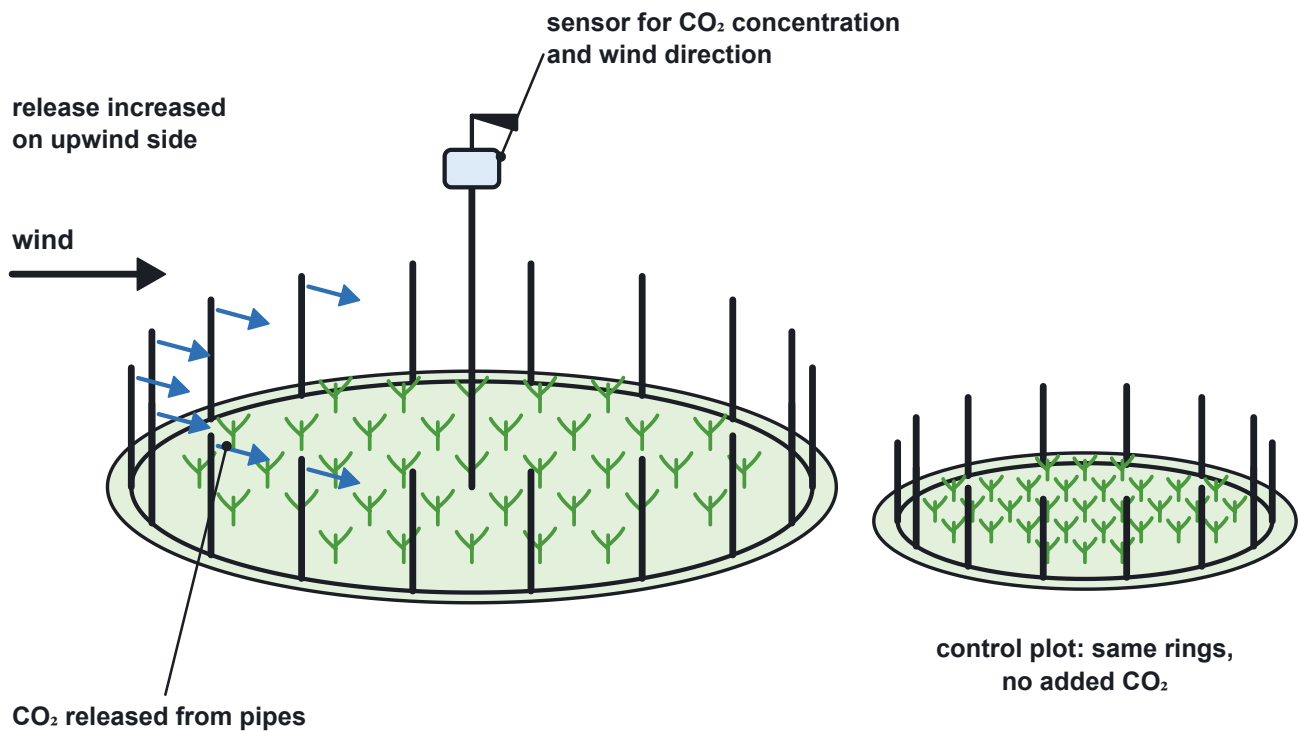
Carbon dioxide enrichment experiments **Spec C1.3.8**

Atmospheric carbon dioxide concentration is rising. **Carbon dioxide enrichment experiments** grow plants at concentrations predicted for the future to find out how rates of photosynthesis and plant growth may change.

Two types of CO ₂ enrichment experiment		
	Enclosed greenhouse experiments	Free-air CO ₂ enrichment (FACE)
Set-up	Plants grown in closed glasshouses or chambers with CO ₂ added to the air	Rings of pipes release CO ₂ around plots in a field or natural ecosystem; sensors adjust the release to hold a target concentration
Control of variables	Easier: temperature, light, water and minerals can be controlled	Harder: weather, soil and pests vary, but affect treated and control plots similarly
How realistic	Less natural: enclosure changes temperature, humidity and wind	More realistic: plants grow in field conditions with other species
Control	Identical greenhouse at current CO ₂	Plots with the same ring structure but no added CO ₂

Higher carbon dioxide generally increases the rate of photosynthesis and growth, at least for a time. However, several FACE studies of crops found **smaller increases** in growth and yield than enclosed experiments had predicted (the size of the gap is still debated). In the field, other factors such as water, temperature or soil nitrogen can become limiting, and the effect of extra CO₂ can shrink over the years.

Practical skill: Be able to identify a controlled variable, such as plant species, light intensity in a greenhouse, or plot size in a FACE experiment. Field experiments are less controlled than laboratory ones, but some questions can only be answered in natural ecosystems.



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A FACE experiment: pipes release CO₂ around a field plot to hold a target concentration; control plots have the same rings but no added CO₂.

Quick check

1. Write the word equation for photosynthesis.
2. Where does the oxygen released by photosynthesis come from?
3. How is an R_f value calculated?
4. What is the difference between an absorption spectrum and an action spectrum?

Quick check answers

Photosynthesis

1. carbon dioxide + water $\rightarrow$ glucose + oxygen
2. The splitting of water.
3. Distance moved by the pigment $\div$ distance moved by the solvent front.
4. An absorption spectrum shows light absorbed by a pigment at each wavelength; an action spectrum shows the rate of photosynthesis at each wavelength.