3.1 Chloroplasts and photosynthesis

Why organisms undergo photosynthesis and how chloroplasts are adapted for their function

Photosynthesis: what is it?

Photosynthesis is a process whereby light energy is converted to chemical energy which can be used to synthesis large, organic molecules from smaller, inorganic substrates. Plants and other organisms which are photosynthetic (for example, bacteria) are known as **autotrophs**, that is, they make organic compounds from small inorganic precursors. More specifically, those autotrophs which undergo photosynthesis are known as *photoautotrophs*. Animals, and many other organisms, cannot synthesise their own food, but instead digest organic molecules. These are known as **heterotrophs**.

carbon dioxide + water → glucose + oxygen

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

Photosynthesis is considered to be the most fundamental biochemical process, as all *aerobes* (organisms which respire aerobically) require the products of photosynthesis to undergo **aerobic respiration**.

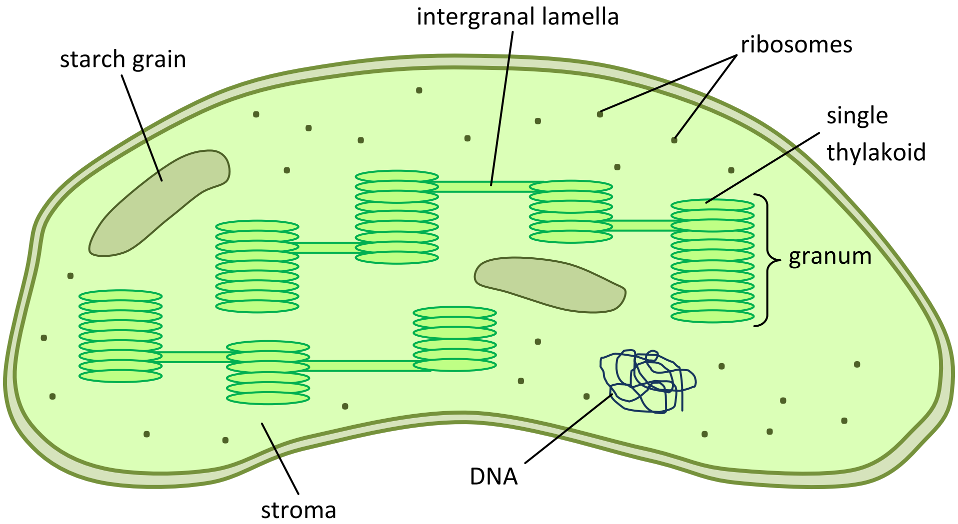
Where does photosynthesis take place?

Photosynthesis is a process which occurs in two stages, both entirely inside the **chloroplast**. A chloroplast is an organelle within photosynthetic cells. The list below outlines some of the adaptations chloroplasts have which help them achieve efficient rates of photosynthesis, and the explanations will become clear to you as you progress through the topic:

- the granal membranes provide a large surface area for the attachment of the photosynthetic pigments (chlorophylls and carotenoids), electron carriers and enzymes for the light-dependent reactions
- a network of proteins in the grana hold the pigments in a very precise manner that forms the photosystems allowing for maximum absorption of light
- the granal membranes have many ATP synthase enzymes attached to them which, via **chemiosmosis** (see 4.4 Electron transport chain) help to manufacture ATP molecules
- the fluid of the stroma holds all of the enzymes needed to carry out the light-independent reactions
- the stroma fluid surrounds the grana, and so the products of the light-dependent reactions can directly and readily pass into the stroma for the light-independent reactions
- chloroplasts contain both DNA and ribosomes so they can quickly and easily manufacture photosynthetic proteins

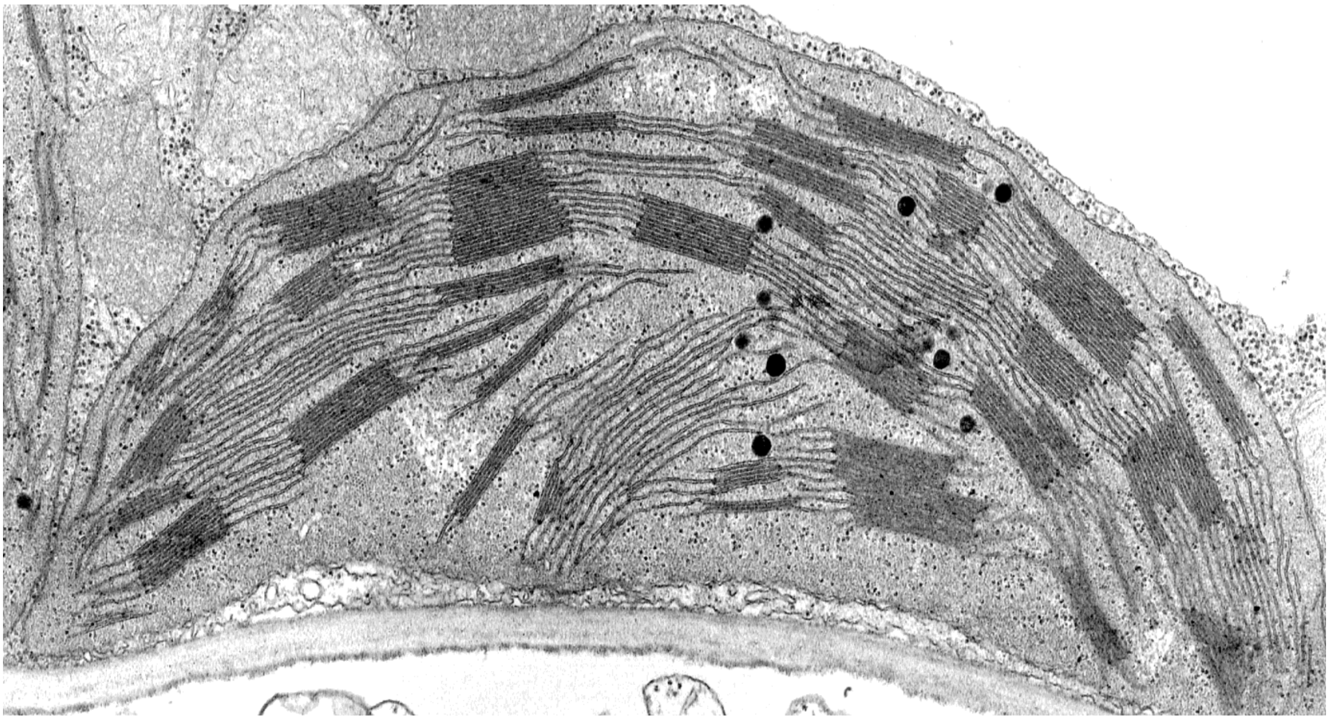
Structure of a chloroplast

Chloroplasts vary, but most are disc-shaped and approximately 2-10µm long. Each has a double membrane (called an **envelope**), consisting of the inner membrane and outer membrane.



Chloroplasts contain stacks of flattened membrane compartments. Each stack is called a **granum** (plural: *grana*) and each compartment is a **thylakoid**. Small, thin membranal extensions connect different grana, called **intergranal lamellae**. The fluid surrounding the grana is called **stroma**. Starch grains can also be found in the stroma matrix, as well as **DNA** and **ribosomes**, which can be used to make proteins.

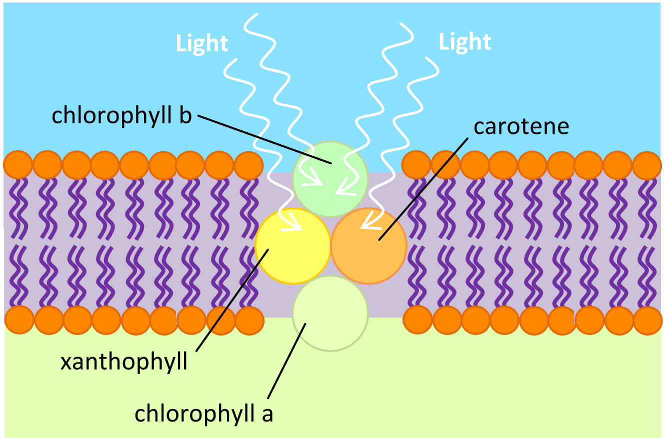
The two stages of photosynthesis are the *light-dependent reactions* (the first or 'light' stage) and the *light-independent reactions* (the second or 'dark' stage). The first stage takes place in the *grana*, and the second stage in the *stroma fluid* of the chloroplast.



Above: transmission electron microscopic image (TEM) of a plant cell chloroplast (x50,000)

Photosynthetic pigments and photosystems

Embedded in the thylakoid membrane among grana are coloured compounds which absorb light of a short range of wavelengths and reflect light of other wavelengths. These are called **photosynthetic pigments**. A photosynthetic pigment can absorb some light energy of specific wavelengths. Various photosynthetic pigments are arranged into small structures called **photosystems** in the granal membrane.



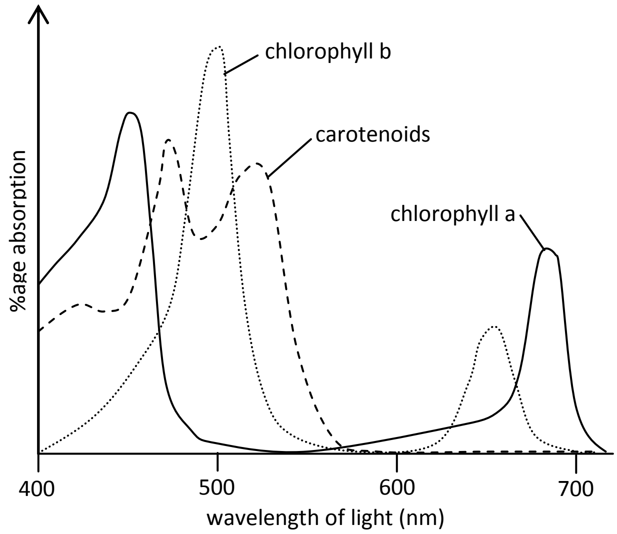
The photosystem shown in the granal membrane in the diagram is made up of four photosynthetic pigments. The pigment closest to the outer membrane is **chlorophyll b**, and the two in the intermembrane space are **xanthophyll** and **carotene**. These three pigments are called the **secondary pigments** (or *accessory pigments*).

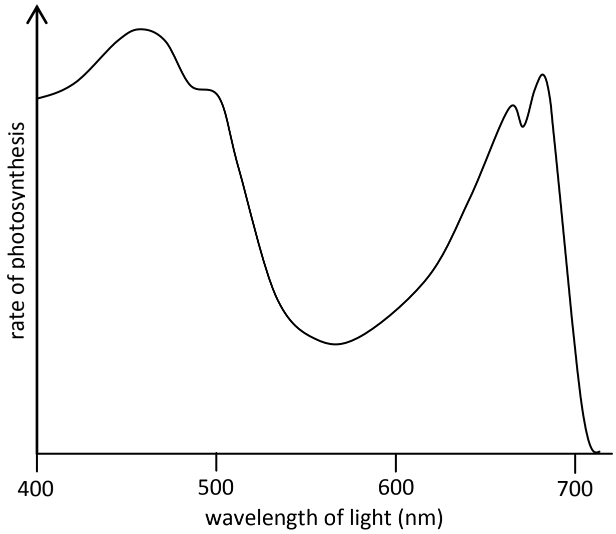
The pigment on the inner membrane to the organelle is called **chlorophyll a**, which is the **primary pigment**. As light hits the secondary pigments which absorb the light, they get excited and a pair of electrons are passed through the pigments and through to the primary pigment.

The table below shows the different photosynthetic pigments and their features:

Pigment	Colour	Peak absorption wavelength (nm)	Function in photosynthesis
Chlorophyll a	Yellow-green	430, 662	Absorbs red and blue-purple light
Chlorophyll b	Blue-green	453, 642	
Carotene	Orange	450	Absorb purple light, protect chlorophylls from damage from light and oxygen
Xanthophyll	Yellow	450-470	

A calorimeter is used to measure the absorption of different wavelengths of light by different pigments. The results of the calorimeter test can be plotted onto a graph called the **absorption spectrum**. Combining the absorption spectra of all photosynthetic pigments gives the **action spectrum** of overall photosynthesis.

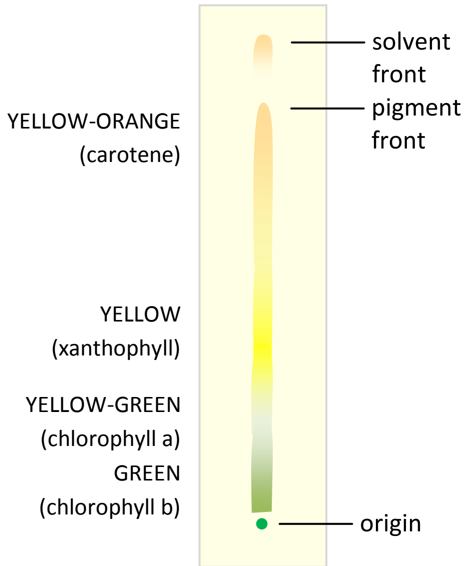




The graph to the left above shows the absorption spectra for photosynthetic pigments, and the diagram to the right above shows the action spectrum for photosynthesis.

Chromatographic separation of pigments

A **chromatogram** can be used to separate the different photosynthetic pigments in a photosystem. Chromatography is a process whereby a mixture of materials are separated by allowing different particles to 'move' (in what is known as the *mobile phase*) along a chromatographic strip and fix along a certain place (in what is known as the *stationary phase*), thus partitioning the different particles.



Using chromatography separates the pigments into colour order, according to the visible light spectrum. We can also use the chromatogram to calculate the **Rf value** (relative front) of various pigments. The Rf value is calculated by dividing the distance between the origin and pigment front by the distance between the origin and the solvent front (i.e. where the solvent stops moving along the chromatography paper).

For example, the pigment xanthophyll may have a relative front of around 0.4 and chlorophyll b around 0.1. It is likely that carotene will have an Rf value of between 0.9 and 1. The carotenoids (carotene and xanthophyll) will travel further along the paper, and therefore have higher Rf values than the chlorophylls, which enter the 'stationary phase' earlier on.

relative front = (origin to pigment front) ÷ (origin to solvent front)