Photosynthesis (chapter 12):

- Photosynthesis is the fixation of CO_2 and its subsequent reduction to carbohydrate, using hydrogen from water, taking place in the chloroplast; where two reactions are involved: light dependent reactions and light independent reactions

$$\underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} \xrightarrow{\text{light energy in the presence of chlorophyll}} \underset{\text{carbohydrate}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2}$$

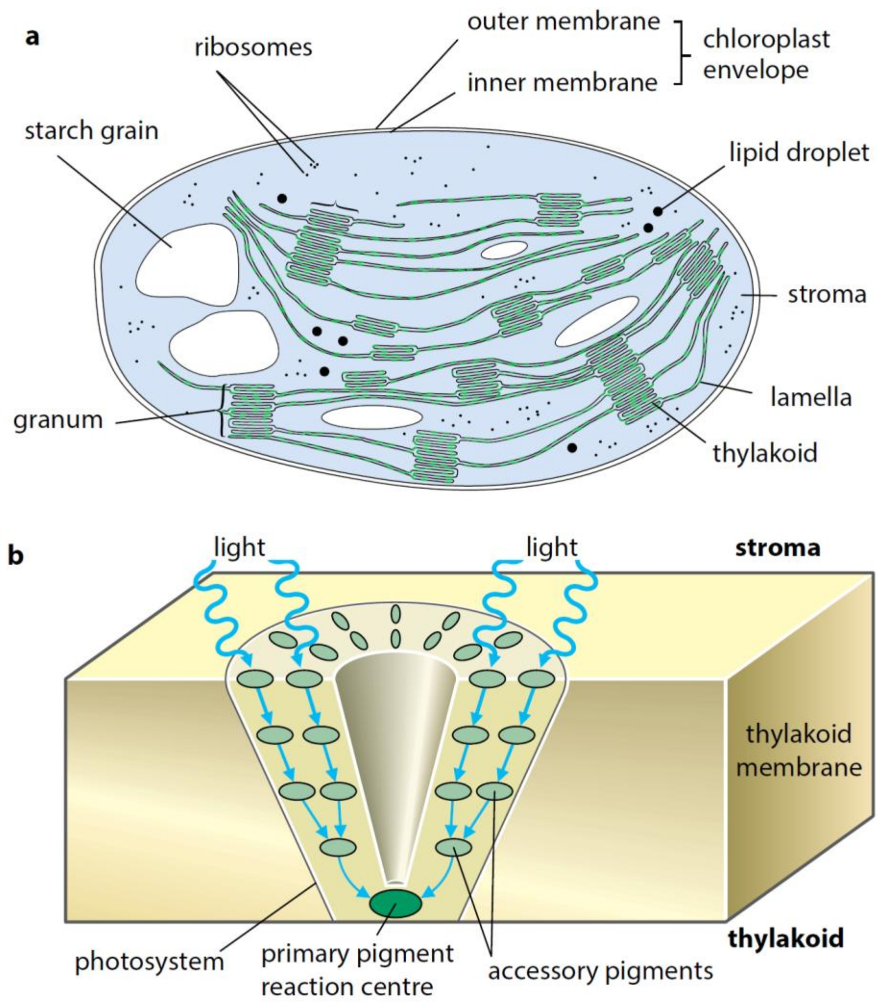


Figure 13.2 **a** A diagram of a chloroplast. **b** A photosystem: a light-harvesting cluster of photosynthetic pigments in a chloroplast thylakoid membrane. Only a few of the pigment molecules are shown.

- The photosynthetic pigments involved fall into two categories: primary pigments (chlorophylls) and accessory pigments (carotenoids) of which are arranged in light-harvesting clusters called photosystems (I and II), where several hundred accessory pigment molecules surround a primary pigment molecule to pass absorbed light energy towards the primary pigment – the reaction centre

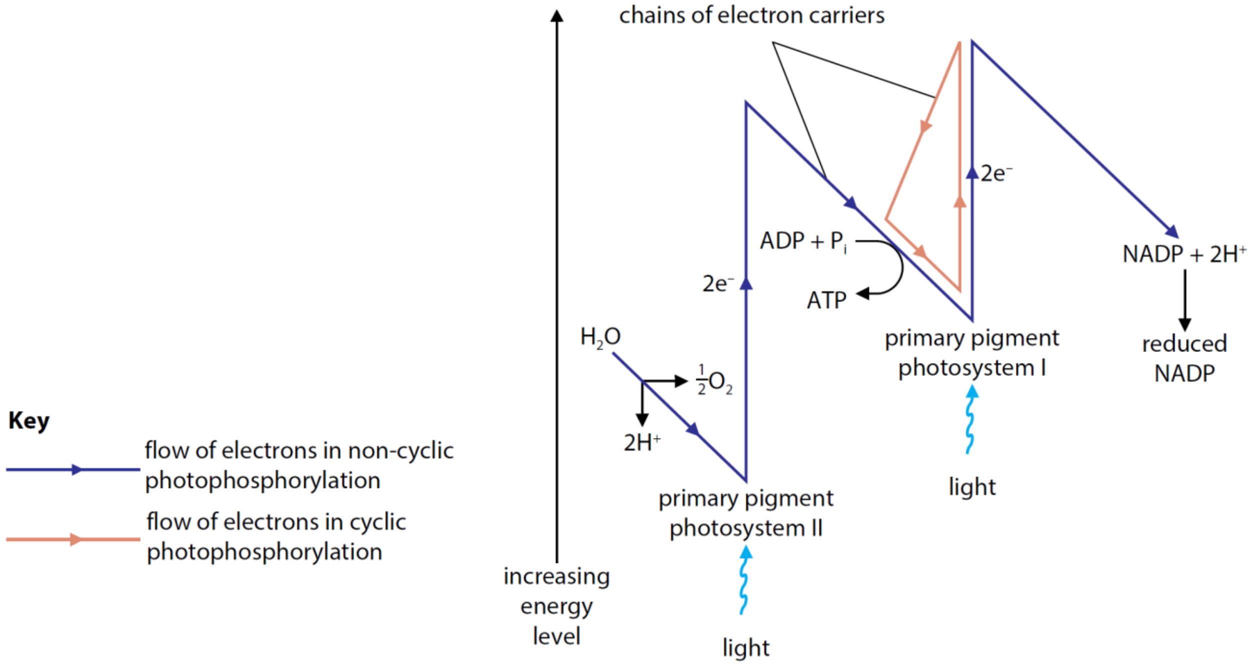


Figure 13.3 The 'Z scheme' of electron flow in photophosphorylation.

- Light dependent reactions – thylakoids (holds ATP synthase):
  - Light energy is necessary for the synthesis of ATP in photophosphorylation and the splitting of water (photolysis – photosystem II) into hydrogen ions (combine with a carrier molecule NADP to make reduced NADP) and oxygen – waste product

$$H_2O \rightarrow 2H^+ + 2e^- + \tfrac{1}{2}O_2$$

$$2H^+ + 2e^- + NADP \rightarrow \text{reduced NADP}$$

  - Photophosphorylation of ADP to ATP are of two types: cyclic and non-cyclic
  - Cyclic phosphorylation:
    - Only involves photosystem I
    - Light absorbed by photosystem I passed to the primary pigment resulting to the excitation of an electron for which is emitted from the chlorophyll molecule (photoactivation) and captured by an electron acceptor to be passed onto the electron transport chain
    - Protons from photolysis pumped into the membrane space to synthesise ATP from ADP and an inorganic phosphate group (Pi) by the process of chemiosmosis for which goes to the light independent stage (Calvin cycle) to produce complex organic molecules
  - Non-cyclic phosphorylation:
    - Involves both the photosystems
    - Light is absorbed by both photosystems resulting to excited electrons emitted from the primary pigments of both reaction centres, which are then absorbed by electron acceptors and pass along the ETC
    - The primary pigment of photosystem I absorbs electrons from photosystem II for which receives replacement electrons from the splitting of water (photolysis)
    - Protons from photolysis pumped into the membrane space to synthesise ATP from ADP and an inorganic phosphate group (Pi) by the process of

chemiosmosis for which goes the light independent stage (Calvin cycle) to produce complex organic molecules

- Light independent reaction (Calvin cycle) – stroma :
    - ➢ Carbon dioxide reaches the inside of a palisade mesophyll cell from the external atmosphere through the stomata by diffusion down a concentration gradient, and passes through air spaces; dissolves in film of water on cell surface then diffuses through cell wall / surface membrane of palisade cells
    - ➢ Using a series of enzyme-controlled reactions:
        - ▪ Fixation of carbon dioxide by combination with RuBP, a 5C compound, (carboxylation) – using Rubisco enzyme – to form an unstable 6C intermediate, resulting to 2 molecules of GP, a 3C compound; using ATP and reduced NADP from the light dependent reaction reduces GP to TP for which most of it regenerates to form RuBP while others undergo rearrangement of carbons to form pentose sugars / lipids / amino acids / hexose sugars; ATP is required for the phosphorylation of ribulose phosphate into ribulose bisphosphate

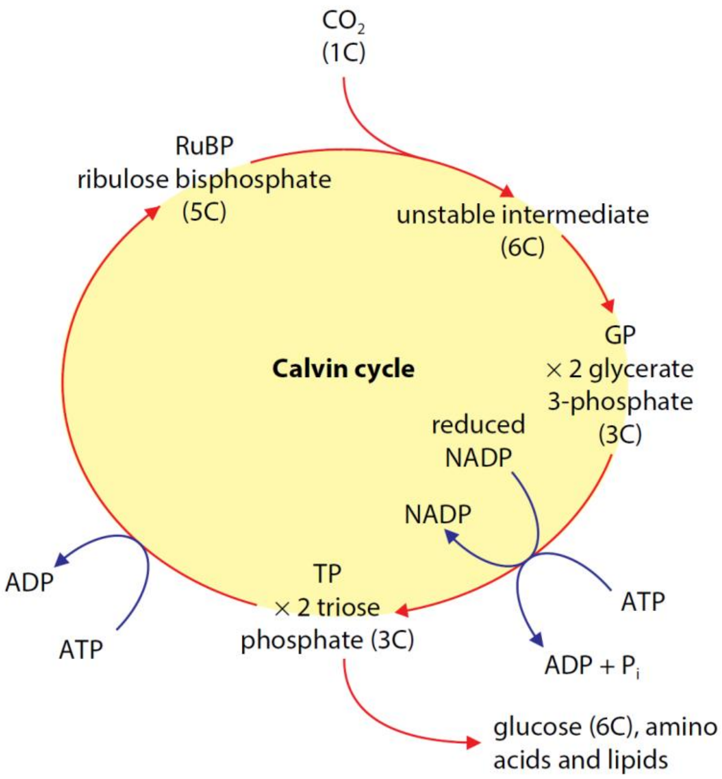


Figure 13.5 The Calvin cycle.

Group	Pigment	Colour
chlorophylls	chlorophyll *a* chlorophyll *b*	yellow-green blue-green
carotenoids	β carotene xanthophyll	orange yellow

Table 13.1 The colours of the commonly occurring photosynthetic pigments.

- Role of accessory pigment in photosynthesis: passes energy to primary pigment; absorb light wavelengths that primary pigment does not; forms part of the light-harvesting cluster of pigments (photosystem)

- Chlorophyll absorb mainly in the red and blue-violet regions of the line spectrum and reflects green light; whereas carotenoids absorb mainly in the blue-violet region of the spectrum
- An **absorption spectrum** is a graph that shows the, absorbance / absorption, of different wavelengths of light by chloroplast pigments
- An **action spectrum** is a graph of the rate of photosynthesis at different wavelengths of light, showing the effectiveness of different wavelengths related to their absorption and energy content

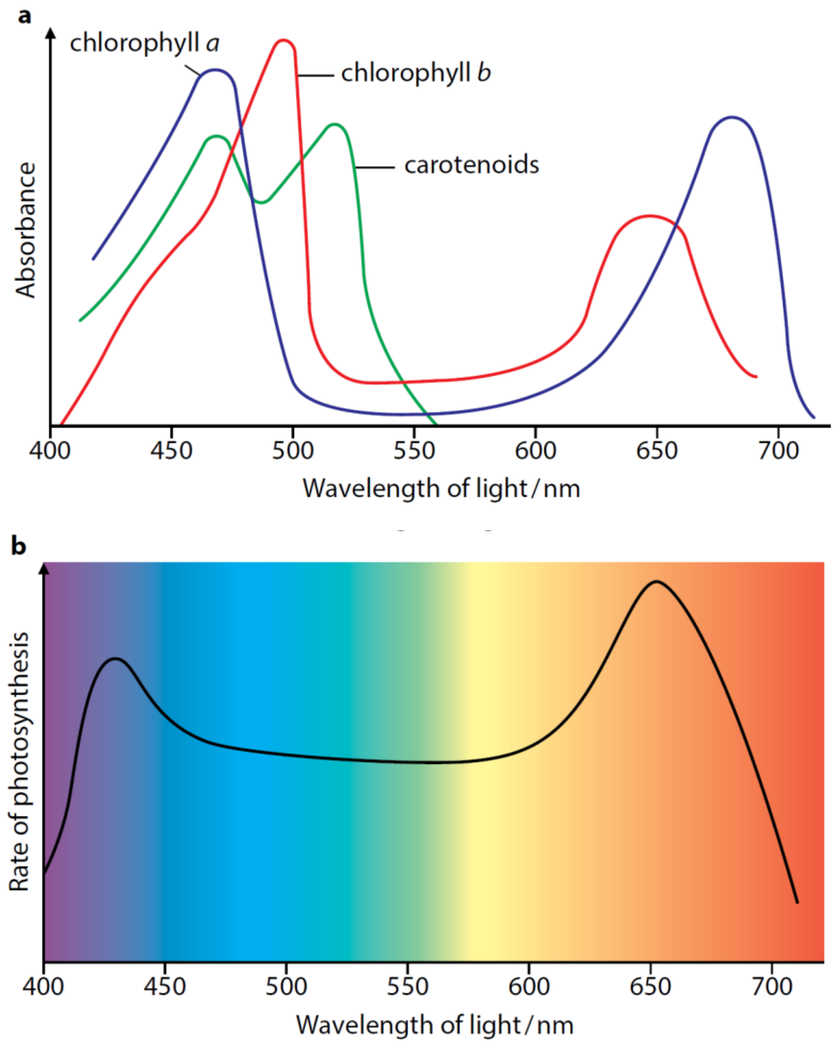
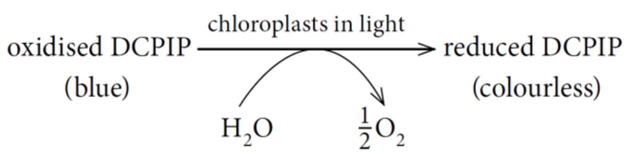


Figure 13.16 **a** Absorption spectra of chlorophylls *a* and *b*, and carotenoid pigments. **b** Photosynthetic action spectrum.

- Investigation to determine the effect of light intensity or light wavelength on the rate of photosynthesis using a redox indicator (e.g. DCPIP) and a suspension of chloroplasts (the Hill reaction):



- The main external factors that affects the rate of photosynthesis: light intensity and wavelength, temperature, and carbon dioxide concentration

- The rate of any process which depends on a series of reactions is limited by the slowest reaction in the series

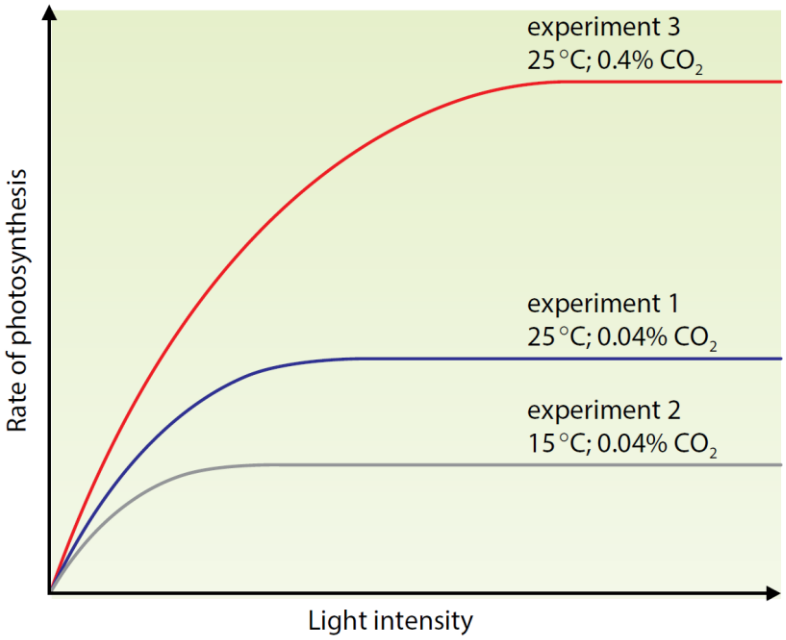


Figure 13.9 The rate of photosynthesis at different temperatures and different carbon dioxide concentrations. (0.04% CO_2 is about atmospheric concentration.)

- Fig 13.9 shows at low light intensities, the limiting factor governing the rate of photosynthesis is the light intensity, but at high light intensity, other factors must be limiting such as temperature or carbon dioxide supply; at low concentrations of carbon dioxide, it acts as the rate-limiting factor, but at higher concentrations, other factors are rate-limiting, such as light intensity or temperature

2 **(a)** Fig. 2.1 shows the effect of temperature on the rate of photosynthesis of a plant at low light intensity and at high light intensity.

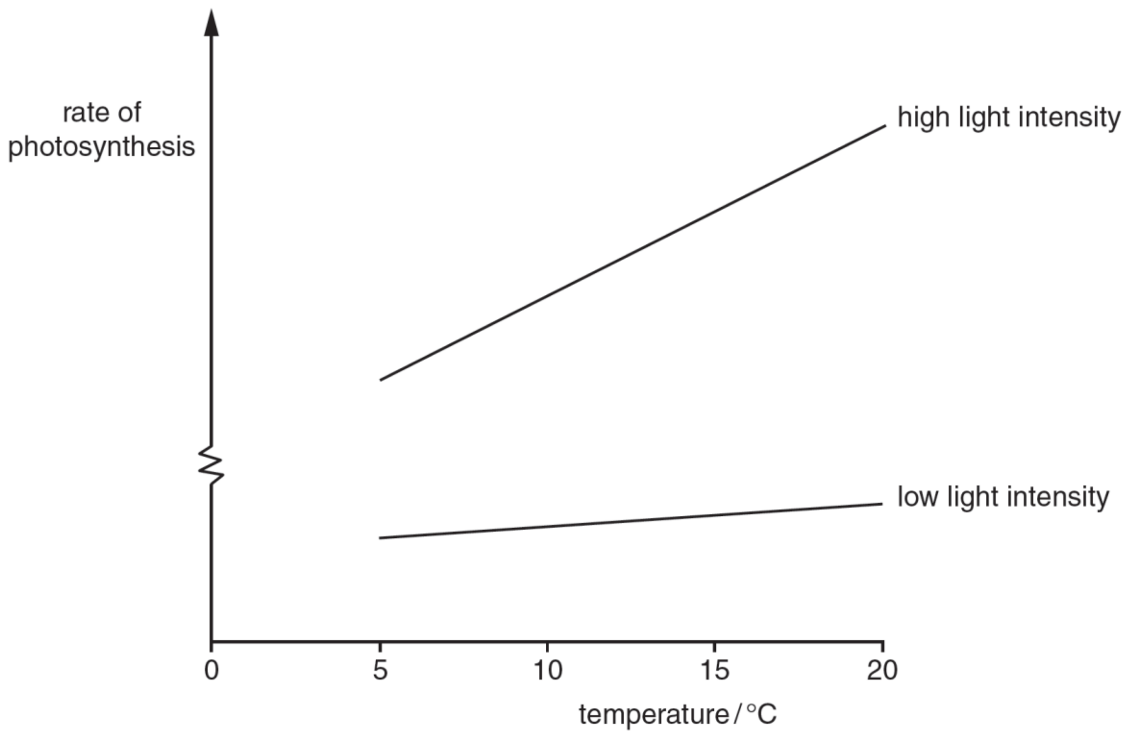


Fig. 2.1

With reference to Fig. 2.1, describe **and** explain the effect of temperature on the rate of photosynthesis.

2 **(a)** *describe*

1 increased temperature increases the rate of photosynthesis at high light intensities ;
2 increased temperature has little effect at low light intensity ;

explain

3 increased kinetic energy ;
4 (leads to) increased, no. of collisions / (rate of) enzyme activity / ESCs / enzyme-subtrate complexes ;
5 (high light intensity) temperature is the limiting factor ;
6 (low light intensity) light intensity is the limiting factor ; [4 max]

- Chromatography – to separate and identify chloroplast pigments and carry out an investigation to compare the chloroplast pigments in different plants (reference should be made to R_f values in identification):
  - Usage of a chromatogram
  - Place spot of pigments on pencil mark at base of the paper
  - Dry and repeat to concentrate spot
  - Dip the paper / chromatogram in the solvent (ethanol) to travel up the paper
  - Measure distance travelled by solvent (front) and pigment (spot)
  - Calculate the R_f value = distance travelled by pigment spot / distance travelled by solvent front
  - Look up / compare results with known R_f values to identify pigments

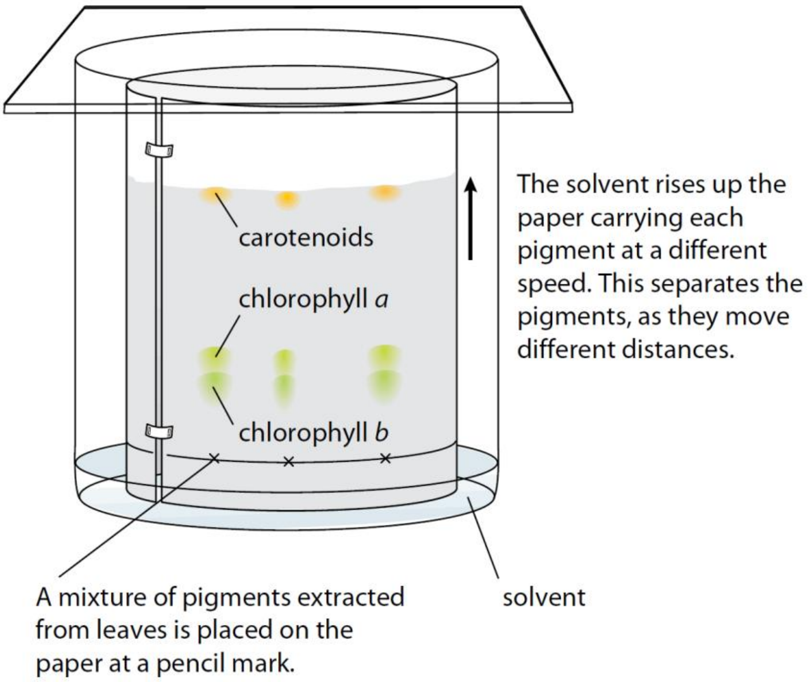


Figure 13.17 Chromatography of pigments in chloroplasts.

- Chloroplasts can move within palisade cells to maximise the amount of light absorption of light and to avoid damage by high light intensities
- In the light independent stage of photosynthesis, carbon dioxide combines with RuBP to form a six-carbon compound, which immediately splits to form two three-carbon molecules (GP), these plants are called C3 plants; However, maize and sorghum plants – and most other tropical grasses – do something different, as their first compound that is

produced in the light independent reaction contains four carbon atoms, therefore are called C4 plants

- Rubisco catalyses the reaction of both carbon dioxide and RuBP; oxygen with RuBP (**photorespiration**), causing less photosynthesis to take place as less RuBP available to combine with carbon dioxide; occurs readily in high temperatures and light intensity
- C4 plants keep RuBP and Rubisco away from high oxygen concentrations in the **bundle sheath cells** around the vascular bundles
- Carbon dioxide is absorbed by the tightly mesophyll cells (so O_2 cannot reach the bundle sheath cells), which contains PEP carboxylase enzyme (has high optimum temperature and does not accept O_2) catalysing the combination of CO_2 with a 3C compound, PEP, resulting to oxaloactetate, 5C, which is converted into malate and passed to the bundle sheath cells – hence maintaining a high concentration of carbon dioxide – for which CO_2 is fixated with RuBP in the light independent reaction; photorespiration is avoided

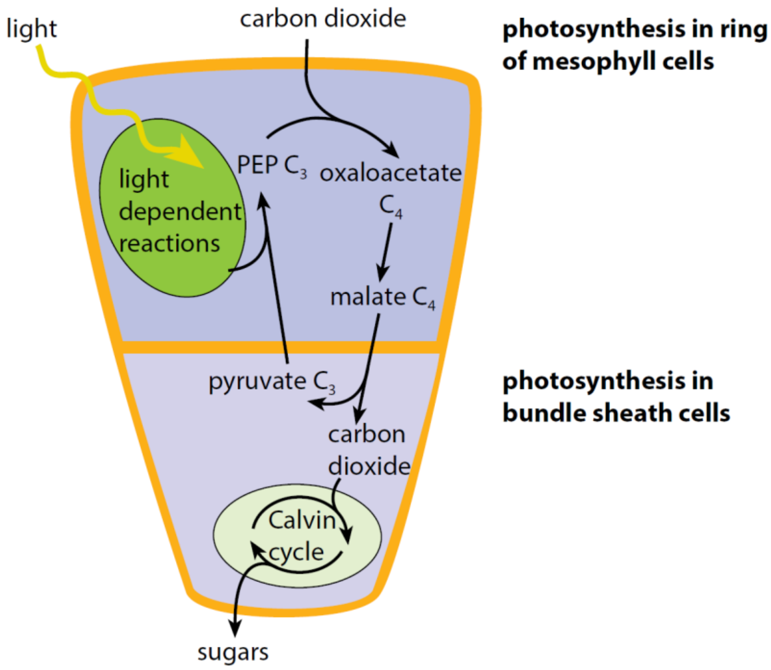


Figure 13.14 C4 photosynthesis.

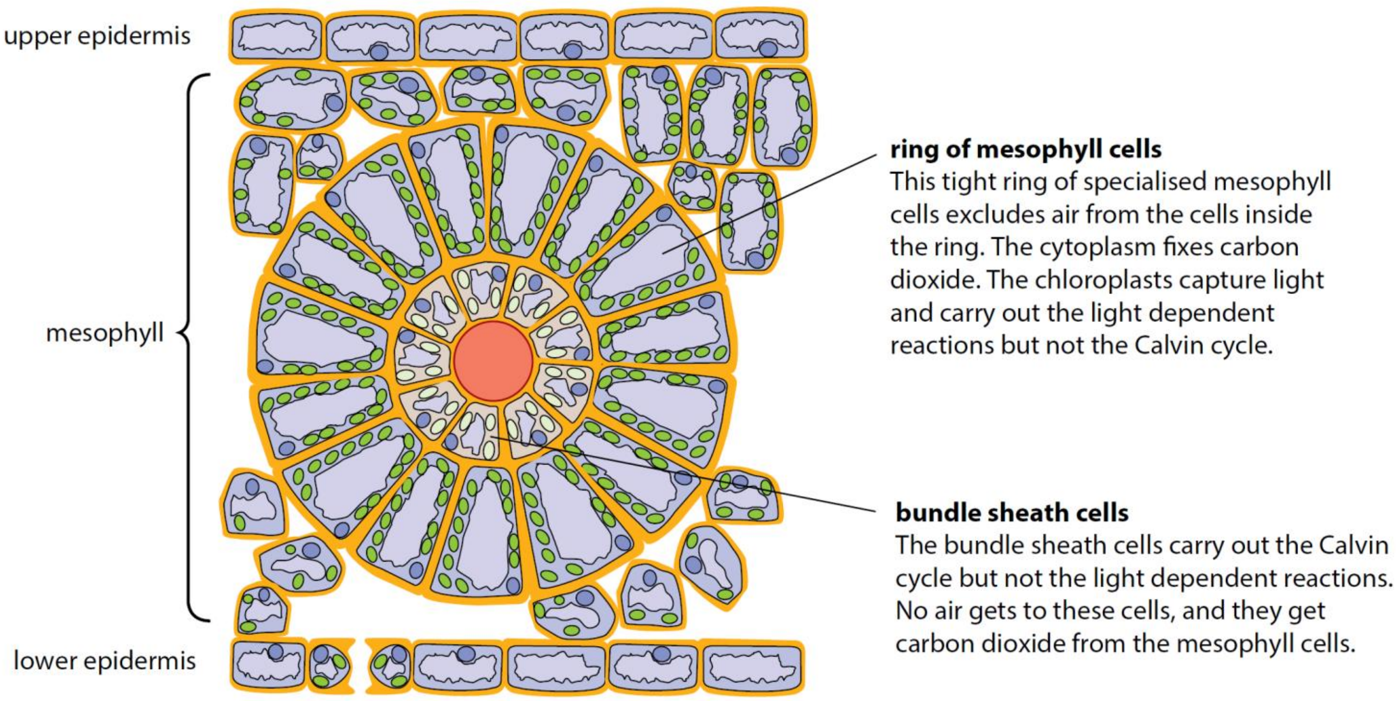


Figure 13.13 Tissues surrounding a vascular bundle of a C4 leaf.

- The high surface area of the thylakoid membrane and the large size and number of grana results to the high absorption of light, hence high photophosphorylation and more chemiosmosis; the large thylakoid space helps increase the proton gradient hence more ATP and reduced NADP produced, thus high rate of light independent reaction