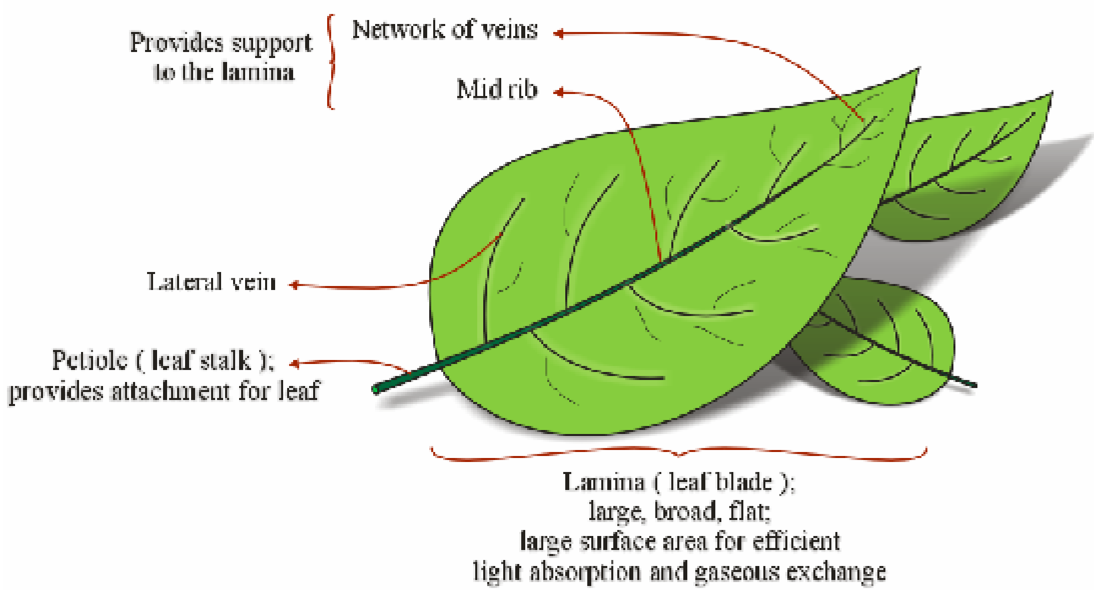
1. Understand that photosynthesis is the synthesis of organic compounds as a result of the fixation and reduction of carbon dioxide (details of intermediate compounds and individual reactions, other than those specified, are not required);

   Photosynthesis is the fixation of carbon dioxide into organic compounds, by green plants, using solar energy and chlorophyll. The CO_2 is reduced using H^+ ions from water.

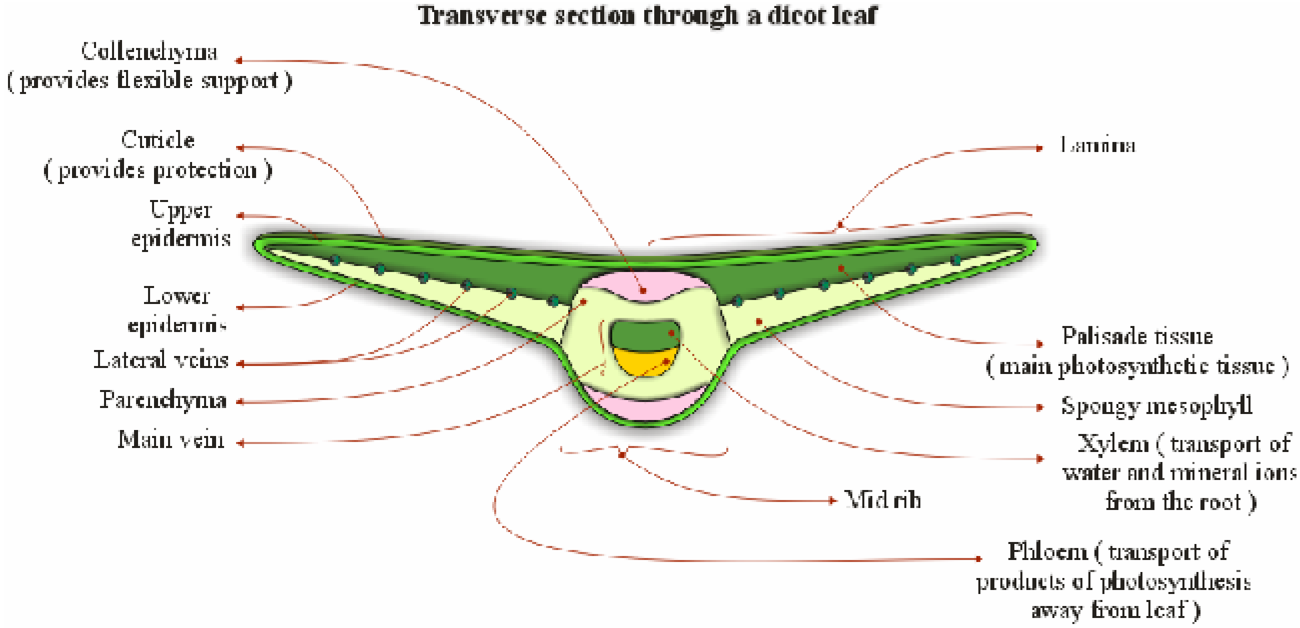
$$\underset{\text{Carbondioxide}}{CO_2} + \underset{\text{Water}}{H_2O} \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} \underset{\text{Carbohydrate (Glucose)}}{(CH_2O)_n} + \underset{\text{Oxygen}}{O_2}$$

2. Describe the external and internal structure of a dicotyledonous leaf; the location of the palisade tissue; recall the structure of a palisade cell;

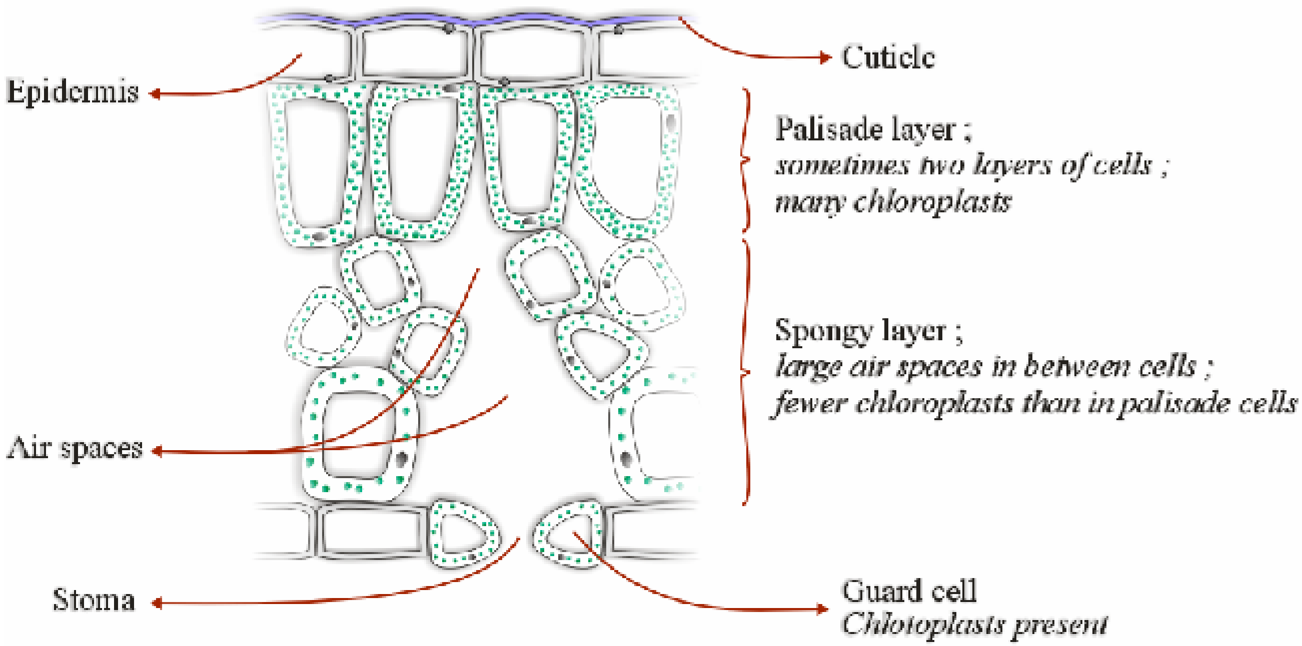
External structure and adaptations in a dicot leaf



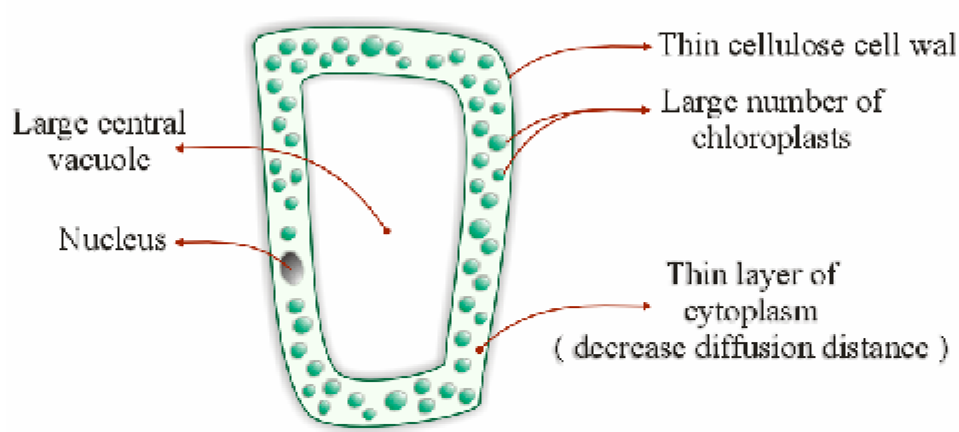
Transverse section through a dicot leaf



Cellular structure of leaf tissue



Single Palisade cell



3. Recall the structure of a chloroplast as revealed by electron microscopy; identify the envelope, stroma, grana and lamellar structure; understand the location of the chloroplast pigments;

- The chloroplast pigments are located in the lamellae (Thylokoid membranes).
- These pigments remain embedded in the Thylokoid membrane.
- Chlorophylls have a polar ' porphyrin' head containing a Mg^{2+} ion and a non-polar long hydrocarbon (phytol) tail. The polar head is attached to the proteins of the thylakoid membranes while the non-polar tail extends into the lipid layer of the membrane phospholipid bilayer.

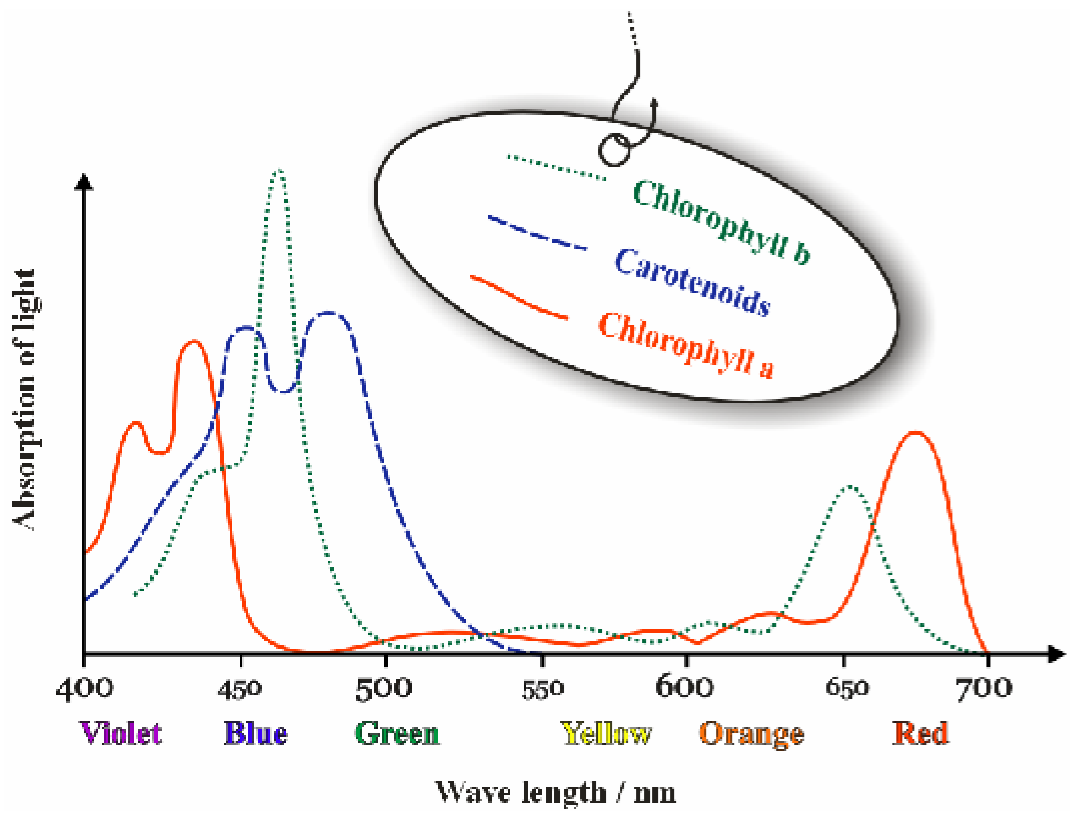
- Chlorophylls, carotenoids and electron carriers are assembled together in the thylakoids membrane to form Photosystems I and PS II.

4. Understand the nature of the chloroplast pigments; chlorophyll a and b; carotenoids; (details of chemical formulae not required); understand absorption and action spectra for chloroplast pigments.

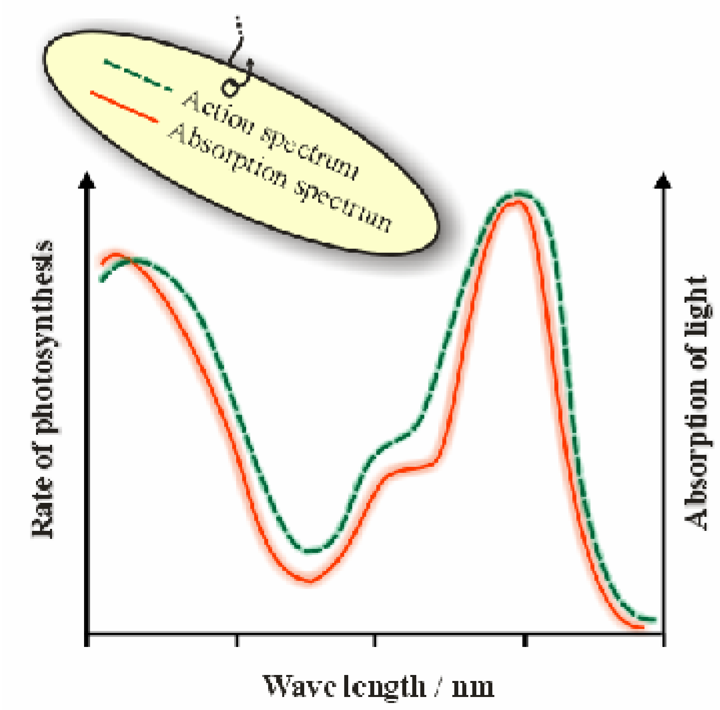
There are several forms of chlorophyll, differing slightly in colour, chemical structure and absorption peaks. Carotenoids are hydrocarbons situated close to the chlorophyll. The table below shows the nature and occurrence of these pigments.

Pigment	Pigment Colour	Wave lengths of light absorbed	Occurrence
Chlorophyll a	Blue - green	Peaks at 420nm (violet) and 660nm (red)	Green plants , Green algae
Chlorophyll b	Yellowish - green	Peaks at 435nm (blue) and 643nm (orange)	Green plants , Green algae
Carotene	Orange - green	Peaks at 425nm (violet) and 480nm (blue)	Green plants , Green algae

- The **absorption spectrum** is a graph that shows how much light a particular pigment absorbs at each wavelength. It is made by subjecting selections of each pigment to different wavelengths of light and measuring how much light is absorbed.



- An action spectrum is a graph that shows the rate of photosynthesis at different wavelength of light. It can be obtained by allowing plants, such as Canadian pondweed, to photosynthesis for a stated time at each wavelength in turn and measuring the volume of gas evolved. A graph is then plotted of rate of photosynthesis against wavelength of light.



- The action spectrum of photosynthesis corresponds closely to the absorption spectrum of chlorophylls and carotenoids.

5. Understand the processes of cyclic and non-cyclic photophosphorylation in the production of reduced NADP (NADPH + H^+) and ATP; the evolution of oxygen.

Photosynthesis takes place in two stages: 1) Light dependent stage
2) Light independent stage

The Light dependent stage:

This occurs on the thylakoid membranes. Photosensitive pigments are organized into Photosystems on the thylakoid membranes. There are two Photosystems:

Photosystem I is smaller and is found on the stromal thylakoids (intergranal thylakoid \ Lamellae)

Photosystem II is larger and associated with granal thylakoids. Both Photosystems are visible as particles on the thylakoid membranes.

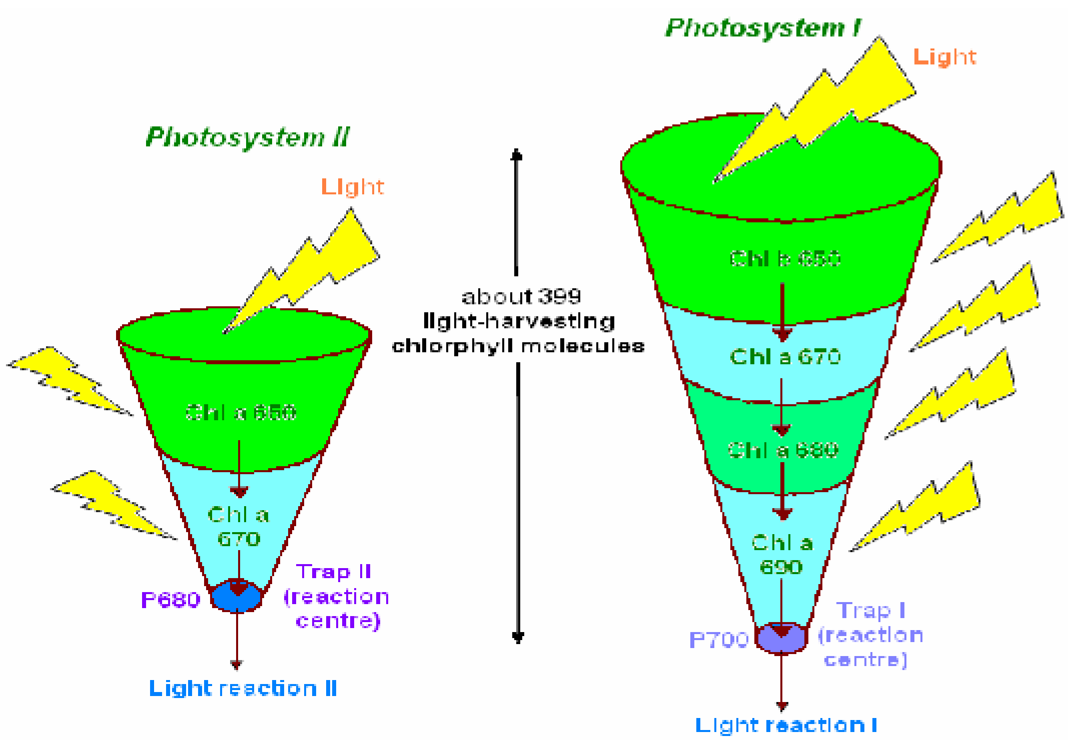
Within each Photosystem there are two types of photosynthetic pigments:
a) Primary pigments   b) Accessory pigments.

Photosystem I

Many molecules of accessory pigments (Chlorophyll b, other forms of chlorophyll a, Carotenoids) are arranged around a chlorophyll a molecule, which has an absorption peak of 700nm.
The **chlorophyll-a** molecule is referred to as the reaction centre and the accessory pigments are referred to antennae pigments.
The antenna complex absorbs light energy and transfers it to the reaction centre (**Chlorophyll-a** molecule). So the reaction centre of Photosystem I is called P700 (P is for pigment).

Photosystem Il

Here also the accessory pigments channel light energy to the reaction centre, which is a chlorophyll *a* molecule with an absorption peak of 680 nm. The reaction centre is called P680.



The diagram shows the relative size of each Photosystem, arrangement of accessory and primary pigments and the channelling of light energy to the reaction centre / primary pigment.

When the **chlorophyll-*a*** molecule at the reaction centre receives light energy, the electrons within the molecule gets excited to form high energy electrons.
These electrons are then emitted by the chlorophyll molecule which are then are then taken up by electron carriers and passed onto other molecules.

Chlorophyll (reduced) —Light energy→ Chlorophyll+ (oxidised) + e^- (electrons)

This is the first step in the conversion of light energy into chemical energy.

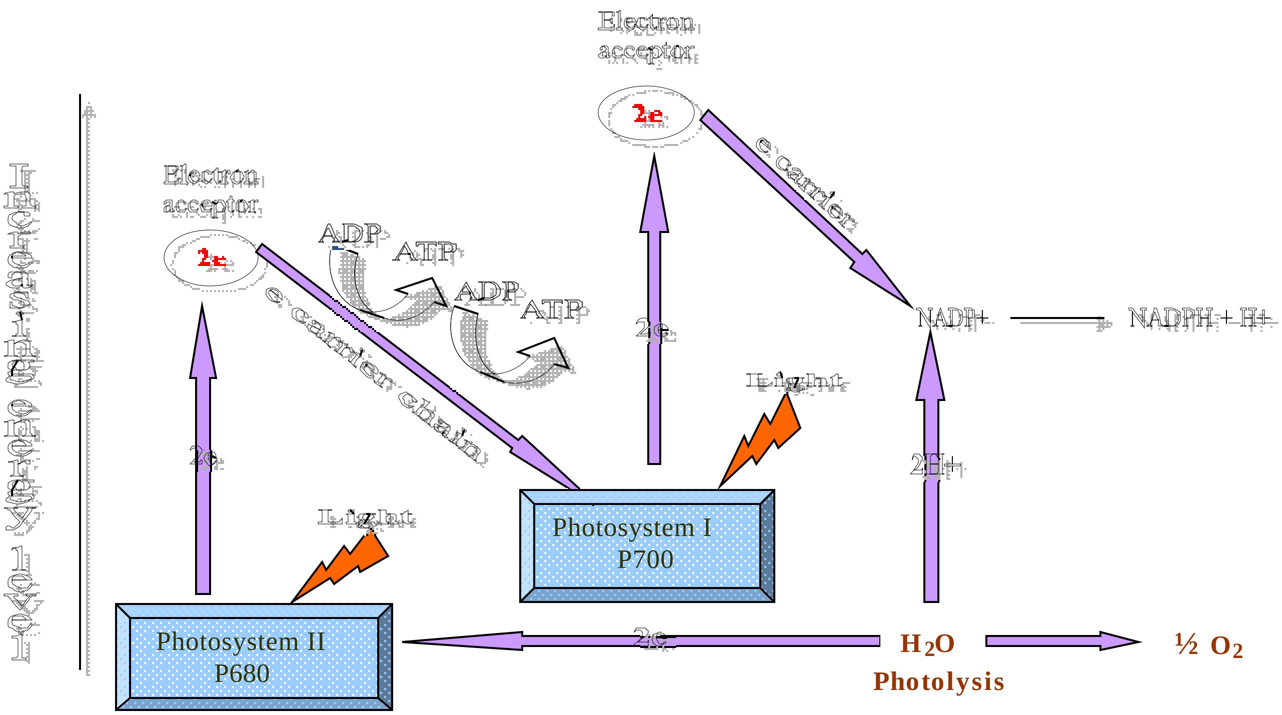
The energy from these high energy electrons is then used to synthesize ATP.

This process is called photophosphorylation. There are two different ways in which ATP can be synthesized by phosphorylation:

- Non-cyclic photophosphorylation
- Cyclic photophosphorylation

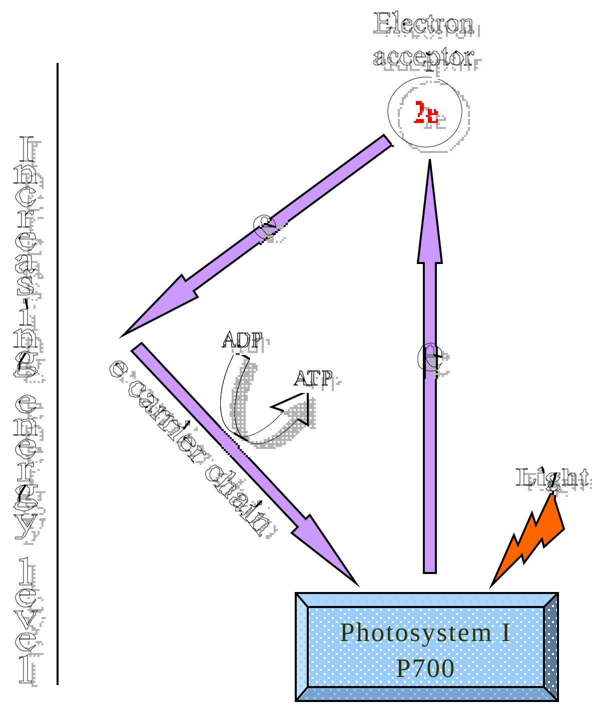
Non-cyclic photophosphorylation.

- Light is absorbed by Photosystem II and passed onto chlorophyll *a* (P680).
- The energized chlorophyll *a* (P680) molecule emits two electrons. These high energy electrons are raised to a higher energy level and are picked up by an electron acceptor.
- The electron acceptor passes the electrons along a chain of electron carriers to Photosystem I. The energy released from the electrons is used to make ATP from ADP + P_i.
- Light is also absorbed by Photosystem I and passed on to chlorophyll *a* (P700). Chlorophyll *a* (P700) also emits 2 electrons.
- The energized electron rise to a higher level and are picked up by a second electron acceptor.
- Since both chlorophylls (P680 and P700) have now lost electrons, they will both be positive and unstable.
- The 2 electrons released from chlorophyll a (P680) of PS II go to replace the two that have been lost by chlorophyll a (P700) of PS1.
- P680 of PSII receives its replacement electrons from the splitting of water (Photolysis). During photolysis, the water molecule dissociates into electrons, hydrogen ions and oxygen. The electrons go to Photosystem II. The oxygen is released as a waste gas.
- The hydrogen ions combine with electrons held by the second electron acceptor to give NADPH. This passes to the reactions of the light independent stage.
- So. The products of the light dependent stage are <u>NADPH</u>, <u>ATP</u> and <u>waste oxygen</u>.



Cyclic photophosphorylation.

- This involves PSI only.
- Light is absorbed by PSI.
- The **chlorophyll-*a*** molecule at the reaction centre receives light and passed onto chlorophyll a (P700).
- This causes the chlorophyll molecule to emit one electron.
- The ‘ energized’ electron is raised to a higher energy level and is picked up by an electron acceptor.
- The electron is then passed along a chain of electron carriers before it is returned to the chlorophyll *a* molecule.
- As the electron passes along the electron



carrier chain, enough energy is released to make ATP from ADP and P_i.

- This ATP is used in the light independent stage. No NADPH is produced in cyclic photophosphorylation.

ATP Production by chemiosmosis in the chloroplast.

During non-cyclic photophosphorylation electrons flow along a chain of electron carriers from Photosystem ll to Photosystem I.
As they do so, they provide energy to pump hydrogen ions from the stroma, across the thylakoid membrane, into the thylakoid space.
This sets up an electro chemical and a concentration gradient, since there are more H^+ ions inside the thylakoid space than there are outside in the stroma.

Hydrogen ions diffuse along this gradient, across the thylakoid membrane and through protein channels. There are special chemiosmotic channels which contain the enzyme **ATP synthetase**. This enzyme catalyses the formation of ATP from ADP + P_i when H^+ ions move through these channels.

6. understand the fixation of carbon dioxide onto a 5C compound (ribulose bisphosphate) to give glycerate 3-phosphate (GP); the use of reduced NADP and ATP from the light-dependent reaction in the synthesis of carbohydrate from GP; the regeneration of the 5C compound.

The light independent stage (Takes place in the stroma of chloroplast).

- This is a cyclic pathway often referred to as the Calvin cycle. The diagram shows a simplified version of the cycle. In reality there are many enzyme-controlled reactions involved.

  The important stages are as below:

- CO_2 combines with a fine carbon compound RUBP. This reaction is catalysed by the enzyme RUBP carboxylase (RUBISCO), which is the most abundant enzyme on earth.

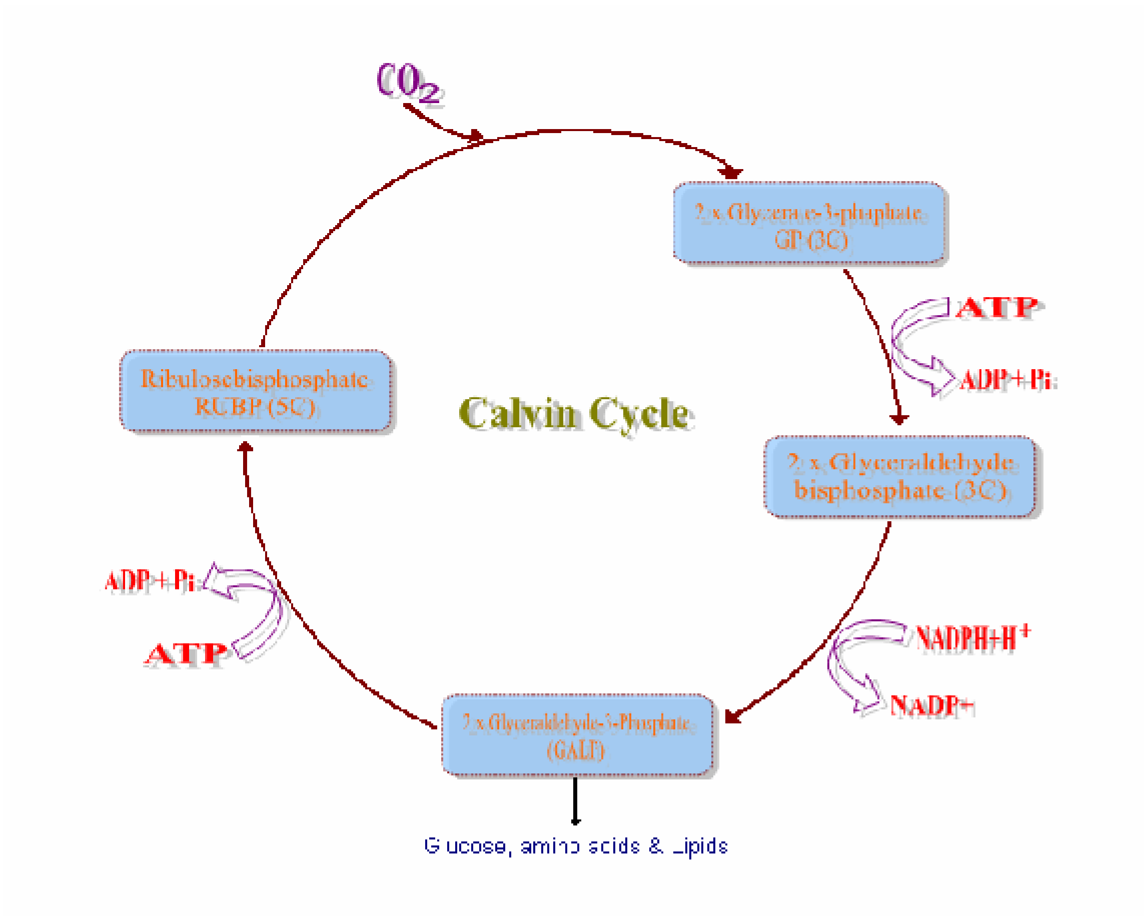
- An unstable six-carbon compound is formed which breaks up to form two molecules of GP.

- ATP (From light dependent stage) is used to phosphorylate the two molecule of GP to produce two molecules of glycerate biphosphate.

- NADPH is then used to reduce each molecule of glycerate biphosphate to glyceraldehyde-3-phosohate (GALP).

- For every six molecules of GALP formed, five and converted into RUBP, through a series of reactions.

- One of the six GALP molecules is converted into glucose, other carbohydrates, lipids, etc.



7. understand the effect of light intensity and wavelength, carbon dioxide concentration and temperature on the rate of photosynthesis;

Effect of light intensity on the rate of photosynthesis.

- Refer to practical on measuring rate of photosynthesis using a Photosynthometer.

- At zero light intensity (in darkness) the rate of photosynthesis is zero. As light intensity increases the rate of photosynthesis also increases, but only up to a certain point. At this point the CO_2 concentration or temperature, must be limiting the rate of photosynthesis.

Example :

- In curve **C**, CO_2 concentration (0.01%) is the limiting factor.
- In the curve **B**, temperature (15 °C) is the limiting factor.
- In the curve **A**, the rate becomes constant because it has reached the light saturation point. This is the maximum rate of photosynthesis. Exposure to light intensities for prolonged periods can destroy Chloroplasts and causes to become bleached.

Effect of CO_2 concentration on the rate of photosynthesis

CO_2 is needed in the light independent stage of photosynthesis (Calvin cycle).

The CO_2 concentration of the atmosphere is about 0.035% or 350ppm (parts per million) by volume.

This is far less than the optimum CO_2 concentration for photosynthesis. Thus CO_2 acts as a limiting factor. It has been shown that by increasing the CO_2 concentration in greenhouses has increased the yield of tomatoes and lettuces.

However, prolonged exposure to CO_2 concentration of above 0.5% can cause closure of stomata.

Effect of temperature on rate of photosynthesis.

Temperature affects the enzymes involve in the Calvin cycle.

Thus it influence the rate of photosynthesis. If other factors are not limiting then a 10°C temperature (Within the range 10-35°C) will lead to a doubling of the rate of photosynthesis.

Usually a temperature of about 25°C is considered as the optimum temperature for photosynthesis.

Increasing the CO_2 concentration and temperature in a glasshouse can be achieved by burning high quantity paraffin (fuel). This burns without producing unwanted fumes and produces CO_2 and heat at the same time.

Effect of wavelength of light on rate of photosynthesis.

Refer to ABSORPTION / ACTION SPECTRUM

8. Understand the concept of limiting factors; compensation point.

Light intensity and compensation point

The point at which the rate of photosynthesis is equal to the rate of respiration is called the light compensation point.

O_2 / sugar produced in photosynthesis synthesis = O_2 / sugar used by respiration

Law of limiting factors

When a process is influenced by several factors, the rate at which the process proceeds is determined by the factor in the shortest supply.

9. Appreciate uptake by roots of mineral ions; understand the function of nitrate, phosphate and magnesium ions.

Uptake of mineral ions by roots - Refer to Unit 2 notes

Roles of mineral ions

Nitrates: (NO_3^-) ;
Essential for synthesis of amino acids, proteins, Nucleic acids, pigment molecules, coenzymes. Deficiency leads to reduced growth.

Phosphate (PO_4^{3-}) ;
Required for synthesis of nucleic acids, phospholipids: component of nucleotides (ATP); Phosphate groups included in phosphorylation of intermediates in metabolism. Deficiency leads to retarded growth.

Magnesium (Mg^{2+}) ;
Constituent of chlorophyll molecule; Activation of enzymes. Deficiency leads to chlorosis (yellowing of leaves).

10. Recall the detection of light in flowering plants by phytochrome pigments; understand the effect of light on the growth of plants;

Refer to UNIT 4 - Phytochromes and photoperiodism

11. Understand the nature of plant growth substances; explain the effects of auxins, cytokinins, gibberellins, abscisic acid and ethene on plant growth; understand the terms synergism and antagonism; understand the commercial applications of auxins.

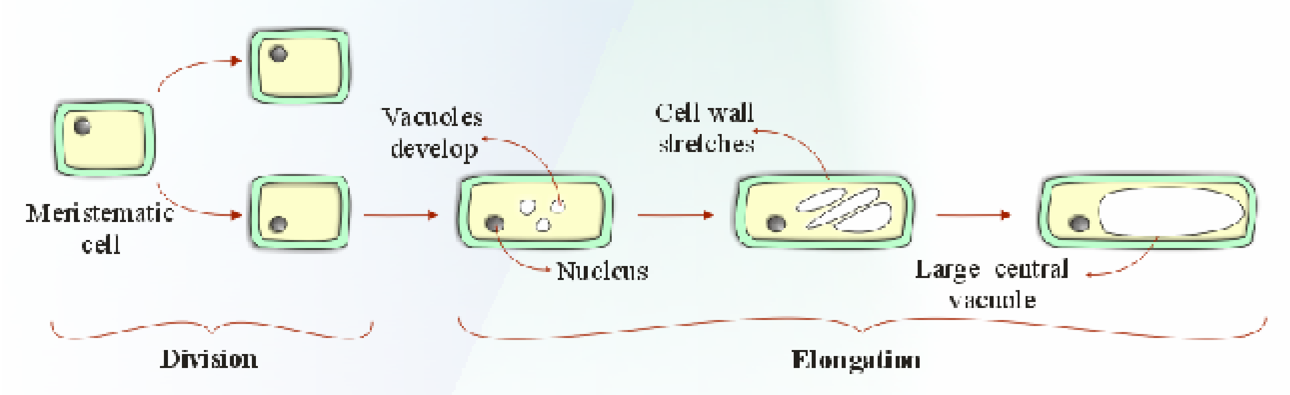
Growth in plants is coordinated by plant growth substances (PGS). These are produced in certain areas of the plant and transported to other parts where they can affect the cell division, cell elongation and cell differentiation.
Plant growth substances are not specific and can affect different tissues and organs in contrasting ways.
For example, High concentration of auxins stimulates cell elongation (growth) in shoots, but, inhibits cell elongation (growth) in roots.
However, low concentration of auxins stimulate growth in roots.

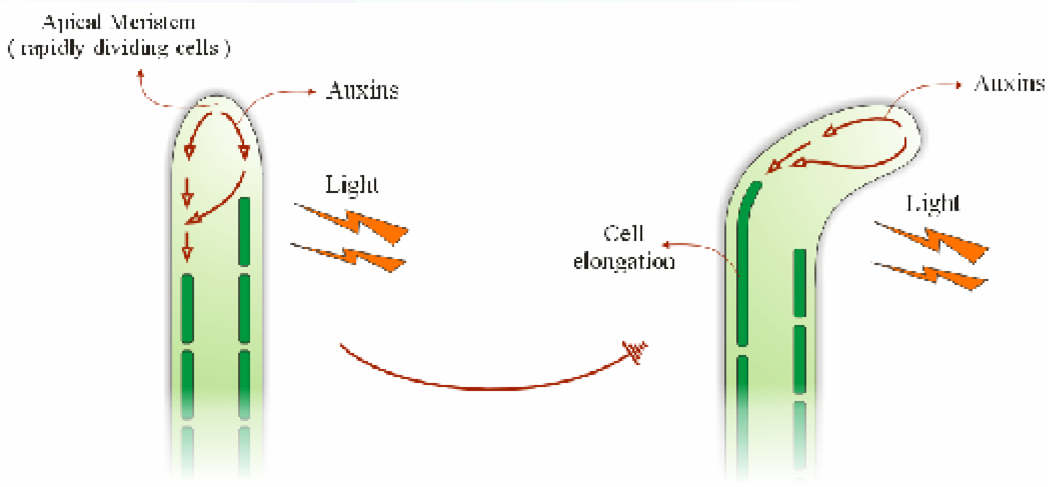
Effect of Auxins on plant growth and commercial applications of Auxins.

Promotes cell elongation

auxins in coleoptile tips cause the coleoptiles to bend towards light (positive phototropism). The auxins move away from the illuminated side of the coleoptile and accumulate on the darker side, where it stimulates cell elongation (growth).

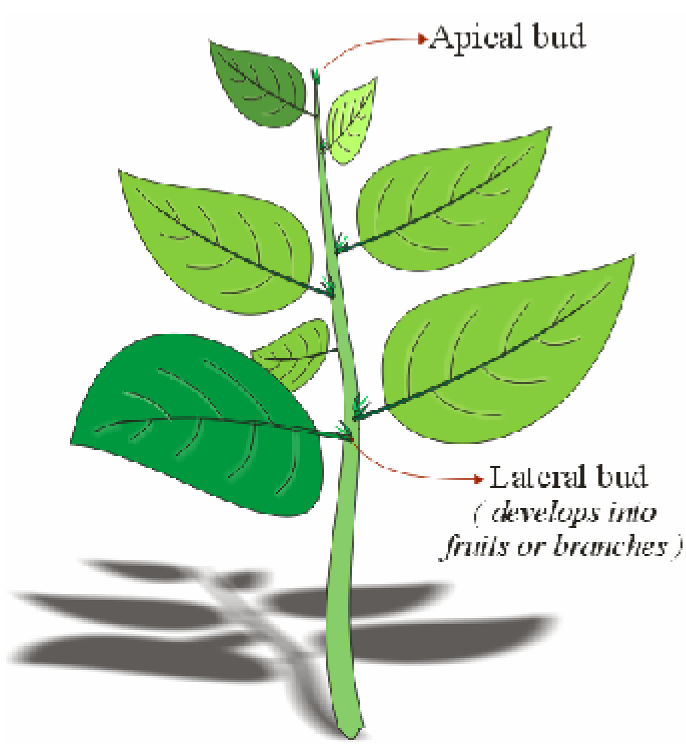
The auxins soften the cell wall. The cell becomes less turgid and takes up more water, resulting in expansion of the cell. Due to the orientation (pattern of arrangement) of cellulose micro fibrils in the cell wall, cell elongation occurs in the longitudinal direction.





Apical dominance:

Auxins from the main apical bud (terminal bud) inhibits the growth of side branches from lateral buds (axillary buds) on stems. This is known as apical dominance. Gardeners usually cut off the apical buds to make plants grow bushy. This process is called pruning.



Rooting in stem cuttings:

Auxins like Naphthalene acetic acid (NAA) and Indole butyric acid (IBA) stimulate the growth of adventitious roots from a stem cutting. Dipping the end of a stem cutting in auxin containing powder dramatically increases the chances of the cutting developing roots and ‘ taking’ . However, excess rooting hormone may inhibit lateral root growth.

Auxins help fruit to set :

spraying of flowers with auxins_greatly increase the natural success rate for pollination and fertilization. It can also bring about fruit formation even in the absence of fertilization. This is called parthenogenesis or parthenocarpy, which results in the formation of seedless fruit.

Abscission of leaves and fruits:

Auxin delays ‘ falling off’ of fruits from the plant. This ensures that the fruit remains on the plant until it is harvested. It also delays abscission in leaves during the early stages but promotes abscission in later stages. If the supply of auxins from the leaves/ fruits exceeds that from the stem, the fruit/leaf remains intact.

Synthetic auxins as weed killers:

Some synthetic auxins disrupt the growth of plant cell. They increase the rate of cellular respiration and cause abnormal growth of internodes and rooting system, leading to death of the plant. These auxins are absorbed much more effectively by broad-leaved (dicotyledonous) plants than by monocotyledons and are therefore particularly useful for removing broad-leaved weeds from monocotyledonous cultures such as lawns and wheat fields.

Effect of Gibberellins on plant growth and commercial applications of Gibberellins.

This was first isolated in the 1930s from a fungus (Gibberella fujikuroi) growing on rice plants. The effects of gibberellins are:

Reversing of genetic dwarfism:

Dwarf varieties of peas and maize plants grow to their normal size when gibberellic acid is applied to it. However, it has no effect on the normal tall variety.

Promotes cell elongation:

Gibberellins increase the length of internodes if sprayed on sugarcane. This increases the yield of sugarcane.

Promotes bolting in long day plants during short days:

Chinese cabbage is the rosette form of the plant which develop during short days. During long days the rosette forms develops into a long flower stalk (bolt). By using gibberellic acid we can bring about bolting during short days.

Remove need for cold period in vernalization:

Carrots need to be subjected to a period of cold for them to flower. Application of gibberellins can remove the need for the cold period to induce flowering (vernalization).

Breaks dormancy in seeds and buds:

Germination of seeds and development of buds is stimulated by gibberellins.

Enzyme production during germination of seeds :

(refer to notes on malting in beer production/ unit 4A option).

Cytokinins :

These are growth regulators found particularly in regions of very active cell division.

They are mostly extracted from seeds (e.g. Zeatin from endosperm of maize/coconut) where they seem to be involved in the growth of the embryo. They stimulate cell division, only in the presence of auxins.
As auxins equally cannot stimulate cell division without Cytokinins, it appears that the two substances interact. They work together to affect the divisions of cells.
This is an important difference between plant and animal hormones, which work independently.
Some other processes, apart from promoting growth by cell division are:

- Delay in leaf senescence (ageing).
- Stimulate bud development.
- Breaks dormancy in both seeds and buds.

Abscisic acid:

This is a growth inhibitor. It has an inhibitory affect on auxins, gibberellins and Cytokinins, and seems to be involved in the production of a weakened area of cells (abscission layer) at the base of a fruit or leaf which finally breaks as the fruit or leaf falls off (abscission).

Other functions involve:

- Retardation of growth in most plants.
- Induces dormancy in seeds and buds.
- Closes stomata in times of water stress.

Ethene:

This is a gas produced in small amounts by plants from the amino acid methionine.
Some of the functions of ethene are:

- Ripens fruits by increasing the rate of respiration.
- Breaks dormancy in buds in some plants.
- Induces flowering in pineapples.
- Promotes abscission in leaves.

Synergism:

If two growth regulators act together and give a greater response than each regulator alone, the interaction is known as synergism.

For example, the effect of auxins on growth is much more dramatic if gibberellins are present as well.

Antagonism:

If two growth substances have opposite effects then it is called antagonism. e.g.: Abscisic acid is usually antagonistic to the effects of auxins.