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.

- 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^+ 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.

There are several forms of chlorophyll, differing slightly in colour, chemical structure and absorption peaks. Carotenoids are hydrocarbons situated close to the chlorophyll.

- 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.

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 II

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.

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.
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>.

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.

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.

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.

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.

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).

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.