PHOTOSYNTHESIS IN HIGHER PLANTS

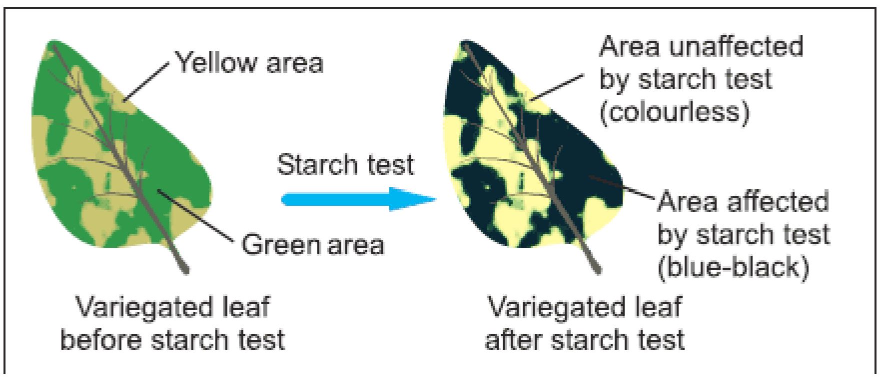
The process of synthesis of organic food (carbohydrates) from CO2 and water in the presence of sunlight is called photosynthesis.

All green plants have the capacity to make food by photosynthesis. It is the most important synthetic process on earth because it is the only source of carbohydrates in which solar energy is fixed in the form of chemical energy. During photosynthesis, the kinetic energy (light energy) of sunlight is transformed into chemical energy and stored in carbohydrate molecules. This chemical energy is used for the growth and sustenance of our biosphere. All animals including human beings depend on plants for their food.

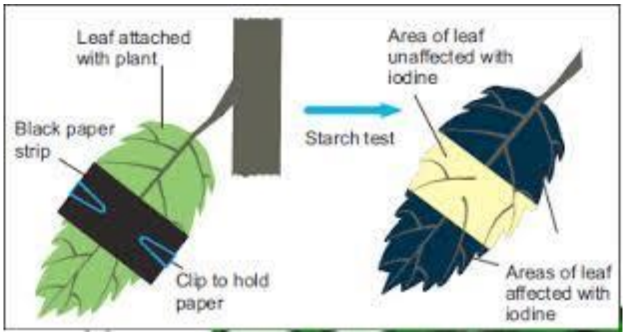
13.1 What do we know: Photosynthesis is the natural physic-chemical process of the world on which the existence of life on earth depends. This photosynthesis is the single most important biological process required for human existence.

Chlorophyll, Light and CO2 are required for photosynthesis. The experiments to prove these are given below.

1. **Variegated leaf experiment**: A variegated leaf is exposed to sunlight. The leaf is then tested for starch. On testing it is clear that white patches appear as colourless because, they do not contain chlorophyll. From this, we assume that chlorophyll is necessary for photosynthesis.



2. **Light screen experiment**: Light screen experiment is used to show that light is essential for photosynthesis. A starved potted plant is taken. A Ganong's light screen or a black paper is attached to one of its leaves. Ganong's light screen is a device which allows circulation of air freely, bit allows light to pass only through a limited area. The plant is now exposed to sunlight for a few hours. The leaf is then removed and tested for starch. It is seen that the area containing starch turned blue while the area without starch remains colourless. Further only the portion of the leaf that was exposed to sunlight turned blue. The part of the leaf which is exposed to sunlight synthesized carbohydrate. The covered portion that was cut off from sunlight did not produce carbohydrate. From this we assume that sunlight is necessary for photosynthesis.



3. **Mohl's experiment**: Mohl's experiment is used to show that CO_2 is essential for photosynthesis. Half part of a starved leaf is passed through a split cork and then introduced into a bottle containing some KOH soaked cotton. The other half is exposed to air. The petiole of the leaf is dipped in water contained in a dish. The set up is kept in sunlight for a period and then tested for starch. It can be seen that starch is formed only in the part of the leaf outside the bottle while the portion of the leaf inside the bottle does not show the presence of starch. The part of the leaf which is outside the bottle gets all the requirements for photosynthesis. Since KOH absorbs CO_2, no starch is formed in the part of the leaf inside the bottle. This shows that CO_2 is necessary for photosynthesis.

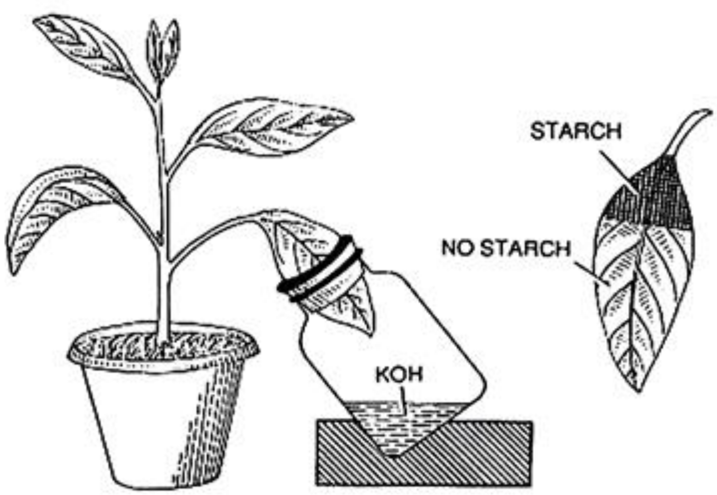
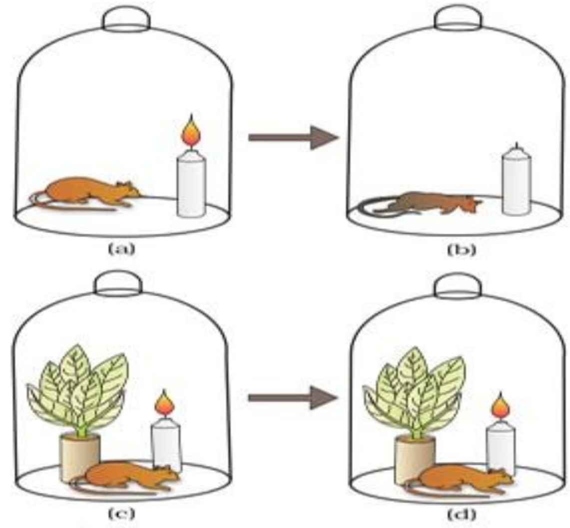


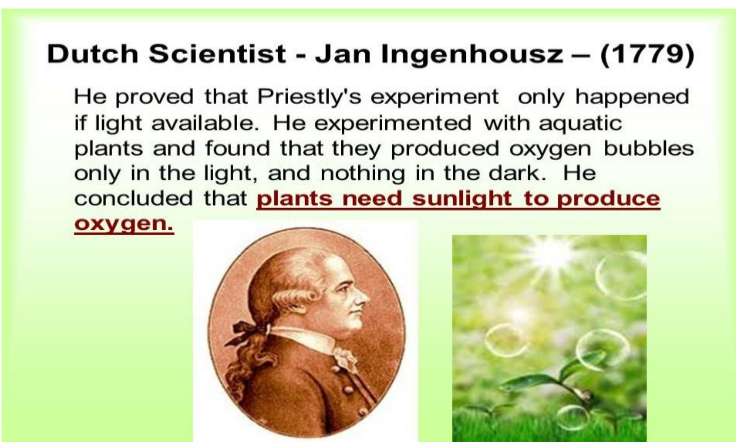
Fig 5.27. Moll's experiment.

13.2 Early experiments: Joseph Priestly in 1774 showed that plants have the ability to take up CO_2 from the atmosphere and release O_2. He carried out an experiment. He took a bell jar and put a mouse and a burning candle into it. He observed that the air inside had changed. It would not allow the mouse to live in it. Then he placed a mint plant in a vessel of water inside the same bell jar. Now he observed that the mouse lived inside along with the burning candle. He came to the conclusion that the vegetation purified the air which he had been made impure by the burning of candle. From this experiment, Priestly hypothesized that the plants restore to the air whatever breathing animals and burning candles remove.

Priestly called the air produced by burning of candles as PHLOGISTON which is noxious for a mouse and said the plants convert it into DEPHLOGISTON.



Jan Ingenhousz stated that green leaves give out dephlogisticated air (air rich in oxygen) in presence of sunlight while in the absence of sunlight (in dark) they give out phlogisticated air (air rich in CO2) and make the air impure.



Julius von Sachs in 1854 discovered that the green plants synthesize glucose and it is usually stored as starch.

T.W Engelmann worked using on *Cladophora* and *Spirogyra*. He noted that when light is split using a prism and used to illuminate the algae, the organism aggregate in the blue and red regions

Van Neil carried out experiments using green and purple sulphur bacteria. He showed that hydrogen released from suitable oxidisable compound reduces CO2 to carbohydrates also put forth that water is the source of oxygen in photosynthesis.

$CO_2 + 2H_2S \rightarrow (CH_2O) + H_2O + 2S$

The Sulphur gas released was from H2S

Van Neil gave a simplified equation of photosynthesis as given below

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

The oxygen released in the above equation is from H2O and not from CO2.

13.3: Where does photosynthesis take place?

In higher plants chloroplast is semiautonomous, endosymbiont with three membrane system. It is made up of three main parts: **Envelope, Matrix and Thylakoid**.

Envelope: It is made up of outer membrane – porins, inner membrane, in between outer and inner membrane is the periplastidal space.

Semi fluid matrix known as **stroma, which contain double stranded circular DNA, 70 S ribosome, Carboxylation enzyme RUBISCO, and PEPcarboxylase enzyme Mg, Cl, Mn etc.**

Thylakoid is membrane lined flattened sac like structure unite to form Grana.

Each thylakoid in grana is known as grana thylakoid, inside it contains the lumen for photolysis of water with the help of Mg, Mn, Cl, Ca and number of electron carriers.

Each grana interconnected with stroma lamellae. Inside it contains space known as fret channel.

Thylakoid membrane possesses 200 to 400 pigment molecule associated with certain protein known as CAB together known as **quantosomes or light harvesting complex**.

Thylakoid membrane also possess F0-F1 particle or coupling factor and number of electron carriers arranged based on their redox potential.

13.4 How many pigments are involved in Photosynthesis?

Photosynthetic unit/ PSU/LHC/Quantosome:

Quantosomes are considered as the unit of photosynthesis and identified by Roderic B Park. They consist of lipids and proteins and are found in thylakoid membrane of chloroplast.

It is the smallest group of pigment molecules which takes part in conversion of solar energy into chemical energy.

It has a photocentre/trap centre/reaction centre which is always a single chlorophyll a molecule which is fed by light harvesting pigments.

They are

- Core molecule-20-30 chlorophyll a molecule around the reaction centre.
- Antennae molecule which absorbs light of shorter wave length. When they absorb light, they get excited and it gives energy to the core, then to the reaction centre by electron spin resonance.

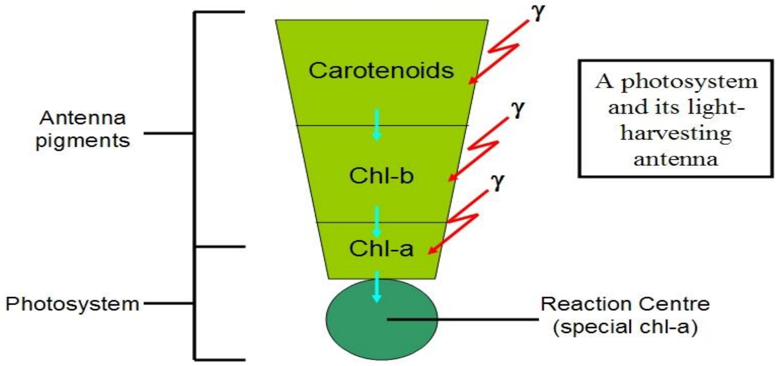
There are two photo systems-PS I and PS II. LHC are made up of hundreds of pigment molecules bound to protein.

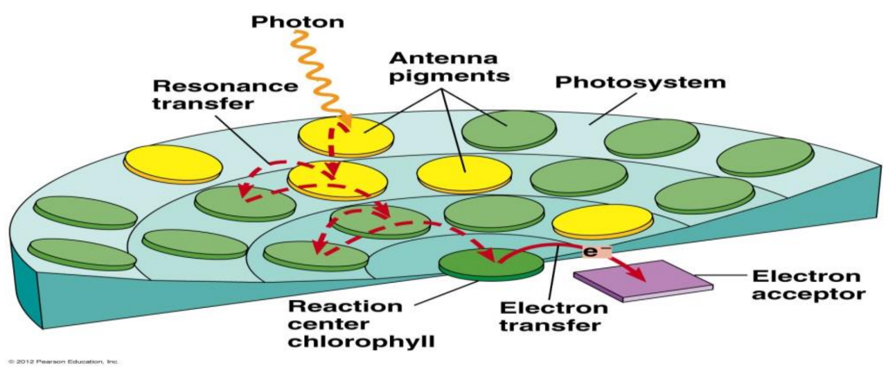
Each PS has all the pigment molecules bound to proteins.

Each PS has all the pigments except one molecule of chlorophyll a forming LH system also called **antenna.**

Single chlorophyll act as reaction centre which is different in both photo systems.

In PS I reaction centre is P700 but in PS II is P680.





Light Harvesting Complex:

200-400 pigments + protein (CAB)

RC + Core molecule + Antenna + protein

Core molecules are PS I and PS II

Photosynthetic Pigments:

There are three main types of photosynthetic pigments-

- Chlorophylls
- Carotenoids
- Phycobillins.

Chlorophyll: Term coined by **Pierre-Joseph Pelletier and Joseph Bienaimé Caventou**.

They are green in colour, water soluble pigment of different types.

- **Chlorophyll a:**

Universal pigment

Present in all photosynthetic organisms except photosynthetic bacteria.

The photosynthetic pigment and accessory pigments absorb light of different wavelength. This energy is transferred to chlorophyll a through electron spin resonance.

They are bluish green in colour.

Dissolves in petroleum ether.

Molecular formula is $\mathbf{C_{55}H_{72}O_5N_4Mg}$

- **Chlorophyll b:**

In all higher plants.

Olive green in colour.

Molecular formula is $\mathbf{C_{55}H_{70}O_6N_4Mg}$

Dissolves in 90% methyl alcohol.

Chlorophyll a is more than chlorophyll b.

- **Chlorophyll c**:

Present in diatom, dino-flagellates and brown algae.

Chemical formula is $\mathbf{C_{35}H_{32}O_5N_4Mg}$

- **Chlorophyll d:**

Molecular formula is $\mathbf{C_{54}H_{70}MgO_6N_4}$

Chlorophyll has a tadpole like configuration with a head porphyrin made up of 4 pyrrole ring together known as tetrapyrole.

A non ionic Mg is held at the centre with 2 covalent and 2 coordination bond.

In chlorophyll a, 3^{rd} Carbon of second pyrrole ring is methyl group but in chlorophyll b, methyl group is replaced by CHO group.

Phytol tail with $C_{20}H_{39}OH$.

Insoluble in water as phytol side chain is composed of insoluble Carbon and Hydrogen atoms, hence to anchor the chlorophyll molecule with thylakoid in chloroplast.

Chlorophyll requires light for synthesis and raw materials are glycine and succinyl coenzyme A.

- **Chlorophyll e**

It is rare.

Yellow in colour.

Seen in *Vaucheria*.

- **Bacteriochlorophyll:**

Seen in bacteria.

Molecular formula is $\mathbf{C_{55}H_{74}O_6N_4Mg}$.

It is very similar to chlorophyll a except for the presence of acetyl group instead of vinyl at the second carbon position of the tetrapyrrole ring.

- **Chlorobium chlorophyll**:

Also known as Bacteriovirdin.

It has hydroxyl methyl group at the second carbon position in the tetrapyrrole nucleus.

Molecular formula is $\mathbf{C_{51}H_{67}O_{64}N_4Mg}$.

- **2.Carotenoids:**

Protect chlorophyll from photooxidation.So known as shield pigments.

They are yellow orange pigments, Water insoluble accessory pigment.

No light is required for their formation.

Absorb blue and violet light.

Commonly are **tetraterpenes**.

Carotenoids are of two types-**carotenes and xanthophylls.**

Carotenes: They are reduced molecules.

Have the general formula $\mathbf{C_{40}H_{56}}$.

Carotenes are of three types

Alpha, Beta and Gamma.

Alpha carotene is present in all plants.

Beta carotene is the abundant precursor of Vitamin A

Gamma carotene in green sulphur bacteria.

Lycopene: Red pigment in tomato and chilly.

Xanthophyll: Yellow brown pigment and are oxygen containing derivative of carotene.

Abundant in *Viola*.

Fucoxanthin in brown algae.

Phycobillins: These are photosynthetic pigments of some algal group structurally related to bile pigments and there are open tetrapyrrole with neither Mg nor phytol.

Only water soluble pigment.

3 Types: Phycoerythrin, Phycocyanin, and allophycocyanin.

These are important accessory pigments in blue green algae and red algae.

They are also called biliproteins.

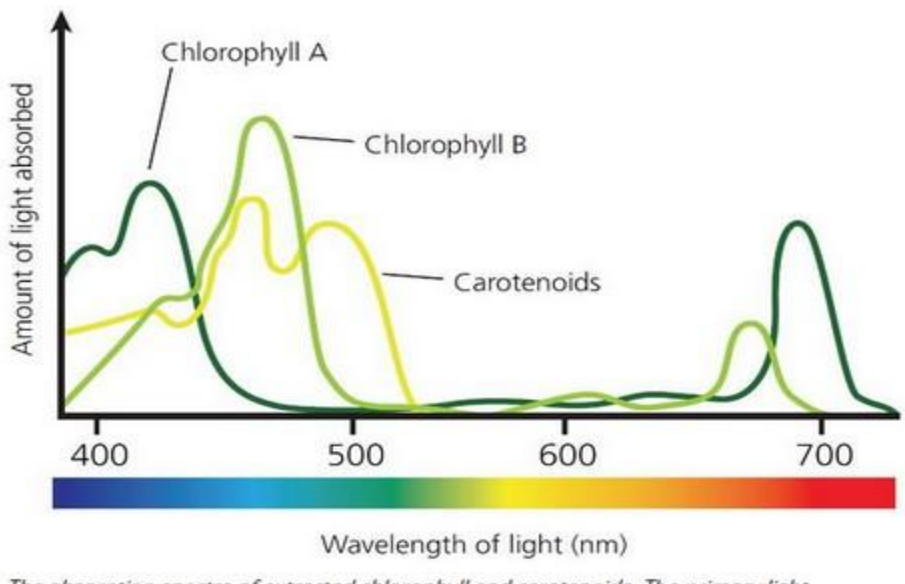
Absorption spectrum: The chloroplast pigments are responsible for the absorption of light.

A particular pigment absorbs light rays with different wavelengths.

For example: chlorophyll a absorbs blue and red lights in the visible spectrum.

The amount of light absorbed by a pigment can be plotted.

The graphic representation of the absorption spectrum (peak) against wavelength is called absorption spectrum.

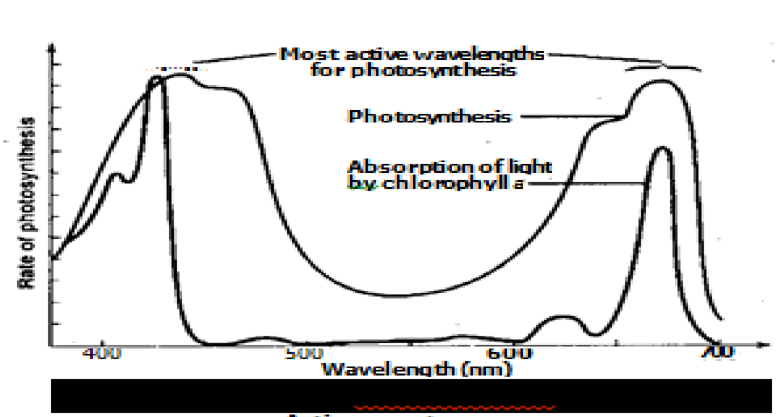


The absorption spectra of extracted chlorophyll and carotenoids. The primary light harvesting chlorophylls absorb light in the blue and red regions. Carotenoids absorb in the blue and green regions.

Action spectrum: Photosynthesis takes place in visible light ranging from 400nm to 700nm wave length.

It does not take place at the same rate with other wave lengths.

The rate of photosynthesis at different wavelengths is measured and plotted by the amount of action. (i.e., oxygen evolution, carbon dioxide utilization). This graphic representation of rate of photosynthesis against wave length is called action spectrum.



Action spectrum

13.5 What is light reaction?

In 1882, T.W.Engelmann plotted the first action spectrum of photosynthesis using green algae, *Cladophora*. The maximum rate of photosynthesis occurs with red light of the visible spectrum.

Most of the photosynthesis takes place in the blue and red regions of the visible spectrum.

Photosynthesis does not take place at the same rate at the other wavelengths of the spectrum.

This happens because, the accessory pigments have only the capacity to absorb light energy and transfer it to chlorophyll a.

The light reaction takes place only in the chlorophyll a (reaction centre).

Mechanism of photosynthesis:

Photosynthesis is an oxidation-reduction reaction in which water is oxidized and carbon dioxide is reduced.

The general equation that represents photosynthesis may be written as

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

The end products of photosynthesis are carbohydrate, water, and oxygen.

Carbon dioxide and water are the raw materials for photosynthesis.

Oxygen is liberated into the atmosphere as a byproduct during this process.

This evolved oxygen comes from water and not from carbon dioxide.

In photosynthetic plants the hydrogen donor is water and the source of oxygen released is also water.

In 1932, Robert Emerson and Arnold proposed that the whole process of photosynthesis involves two distinct phases. They are photochemical phase and biosynthetic phase.

Photochemical phase or Light Reaction:

It is the light dependent phase of photosynthesis in which ATP and NADPH are formed in the presence of light.

It takes place in the grana of the chloroplast. It takes place in the presence of sunlight.

It consist of the following steps:

a. Light absorption

b. Water splitting

c. Oxygen release

d. Formation of high energy chemical intermediates (ATP and NADPH).

In 1935, Robert Emerson proved that two pigment systems are involved in light reaction.

They are pigment system I (photo system I and P.S.I) and pigment system II or P.S.II).

The reaction centre and the light harvesting system (accessory pigments) together form photosystem or pigment system. **About 250 to 450 pigment molecules constitute a single photosystem.**

Photosystems are functional and structural units consisting of protein complexes involved in photosynthesis.

They are located in the thylakoid membranes of plants and algae or in the cytoplasmic membrane of photosynthetic bacteria.

Two kinds of photosystems are present-Photosystem I and Photosystem II.

Both photosystems are required for oxygenic photosynthesis.

The photosystem II is located in the appressed region of granal thylakoids.

PS I is found in the non-appressed region of grana and stroma thylakoids.

13.6 The Electron Transport:

Noncyclic photophosphorylation:

It is also termed as Z scheme.

Both PS I and PS II are involved.

PS II consists of Chlorophyll a 660, Chlorophyll a 673, Chlorophyll a 690, Chlorophyll b, Chlorophyll c, or Chlorophyll d, carotenoids, and phycobillins.

Chlorophyll a 680 is the reaction centre.

It occurs in stroma lamellae.

The electron do not go back to the reaction centre but rather are accepted by NADP+.

Photolysis of water uses up the electrons and leads to the formation of ATP and NADPH2.

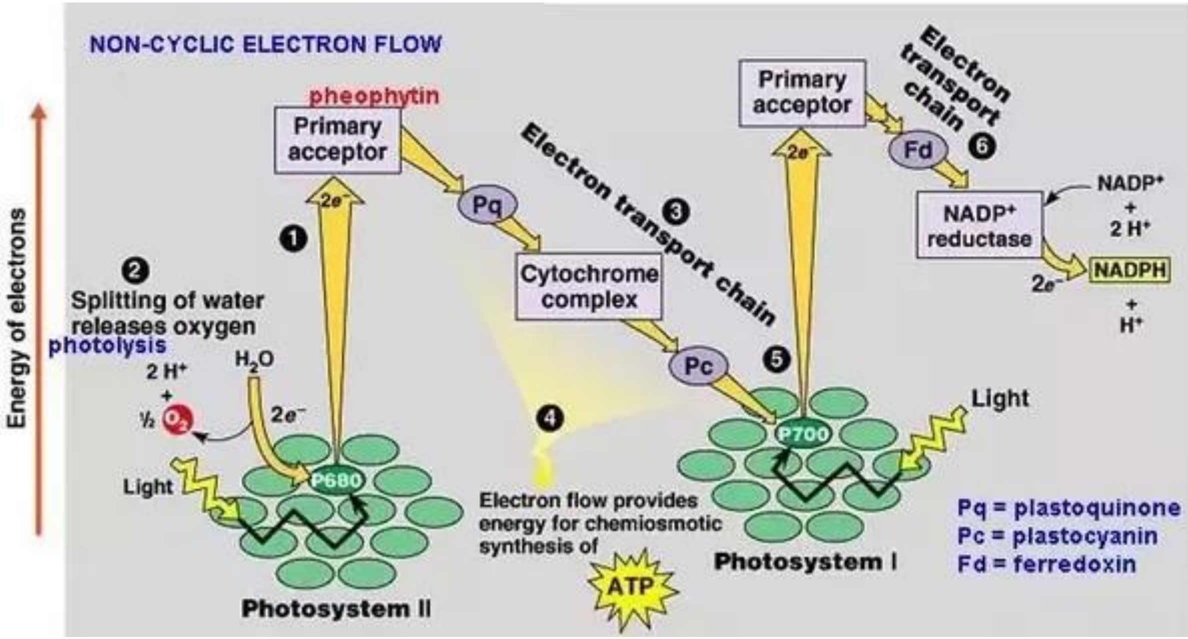
The steps in the process begin with the PS II.

Electrons are passed to **plastoquinone reducing substance (PQRS)**.

PQRS passes them to **plastoquinone which passes them to the cytochrome system.**

The cytochrome system passes them to **plastocyanin which in turn passes them to PS I.**

The steps afterwards include **FRS, Ferredoxin, and NADP reductase.**



13.6.1 Photolysis of water: P680 becomes a strong oxidizing agent and splits a molecule of water to release oxygen.

This light dependent splitting of water molecule is called photolysis of water.

Manganese, Calcium and chloride ions play important roles in the photolysis of water.

The photolysis of water in photosynthesis was first demonstrated by Robert Hill in 1937.

Water is splitting into hydrogen ions, oxygen and electrons. Oxygen is one of the end products of photosynthesis.

13.6.2 Cyclic photophosphorylation and noncyclic photophosphorylation:

Also known as Light reaction/Hill reaction/Photochemical reaction/ Generation of assimilatory powers/Photophase.

In cyclic photophosphorylation only PSI works.

PS I consists of Chlorophyll a 670, Chlorophyll a 683, Chlorophyll a 695, carotenoids, some molecules of chlorophyll b and reaction centre a 700 or P 700.

This form of photophosphorylation occurs on the thylakoid membrane.

The electron begins PS I, passes from the primary acceptor to **ferredoxin reducing substance (FRS),**

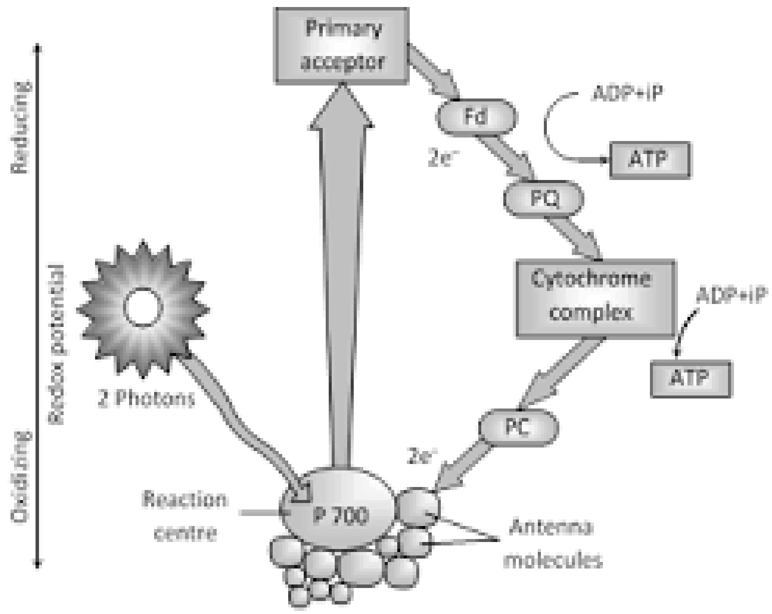
Then to ferredoxin, then to cytochrome b6f and then to plastocyanin before returning to PS I.

This process produces a proton motive force, pumping H^+ ions across the membrane thereby generating a concentration gradient that can be used to power **ATP synthase during chemiosmosis.**

Cyclic photophosphorylation neither produces O2 nor NADPH.

NADP+ does not accept the electrons, they are instead sent back to cytochrome b6f complex.

This process is mostly seen in bacteria and favoured in anaerobic condition.



Cyclic photophosphorylation

13.6.3 Chemiosmotic hypothesis:

ATP synthesis in the chloroplast is explained by chemiosmotic hypothesis.

It was proposed by **Peter Mitchell in 1961.**

According to chemiosmotic hypothesis, **during photosynthesis, a proton gradient is developed across the thylakoid membrane.**

Protons are accumulated towards the inside of the thylakoid membrane in the thylakoid lumen.

The proton gradient is caused by 3 ways:

1. Water molecule is broken up into H^+ and OH^- on the inner side of the thylakoid membrane.

As a result H^+ are accumulated within the thylakoid lumen.

2. When the electron move through the photosystem I and photosystem II, H+ are transported across the thylakoid membrane.

Primary electron acceptor is located towards the outer side of the thylakoid membrane.

This primary electron acceptor transfers its electron to an H carrier and not to an electron carrier directly.

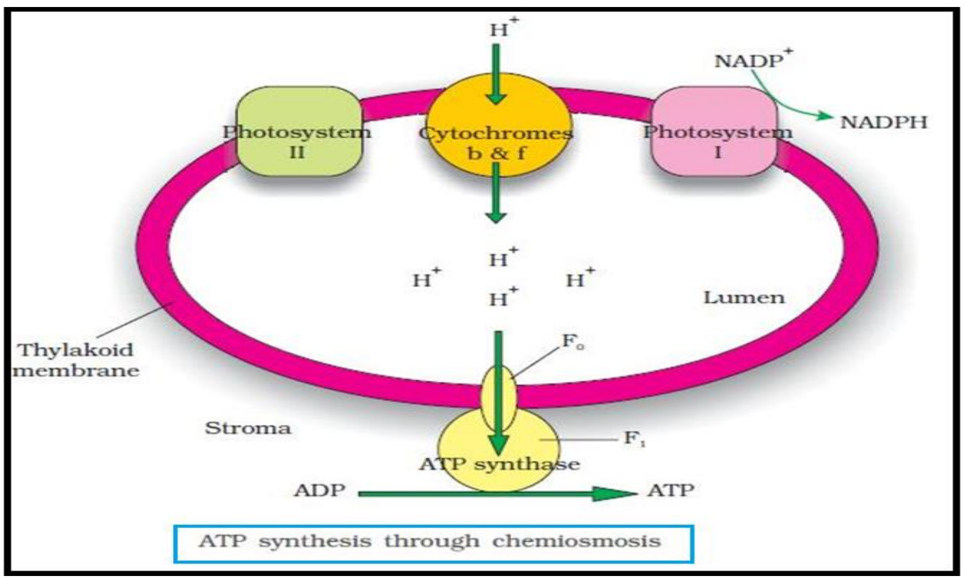
This hydrogen carrier molecule transfers the electron to the electron carrier (cytochrome b, cytochrome f etc.) on the inner side of the thylakoid membrane and removes a H^+ ion from the stroma while transporting an electron. This proton is released into the inner side of the thylakoid membrane.

3. NADP reductase enzyme is located on the stroma side of the thylakoid membrane. When electrons come from the electron acceptor of PS I, H^+ are necessary for the reduction of $NADP^+$ to NADPH + H^+. These H^+ are removed from the stroma.

By these ways within the chloroplast, H^+ are accumulated in the thylakoid lumen and are decreased in number in stroma.

This creates a proton gradient across the thylakoid membrane. As a result, pH is decreased in the thylakoid lumen.

The proton gradient is broken when the protons move to the stroma through the transmembrane channel of the F0 of the ATPase enzyme across the thylakoid membrane.



ATPase enzyme has two parts.

The base of the ATPase is called F0 and head piece is called F1,

F0 forms a transmembrane channel which is embedded in the thylakoid membrane on the side that faces the stroma.

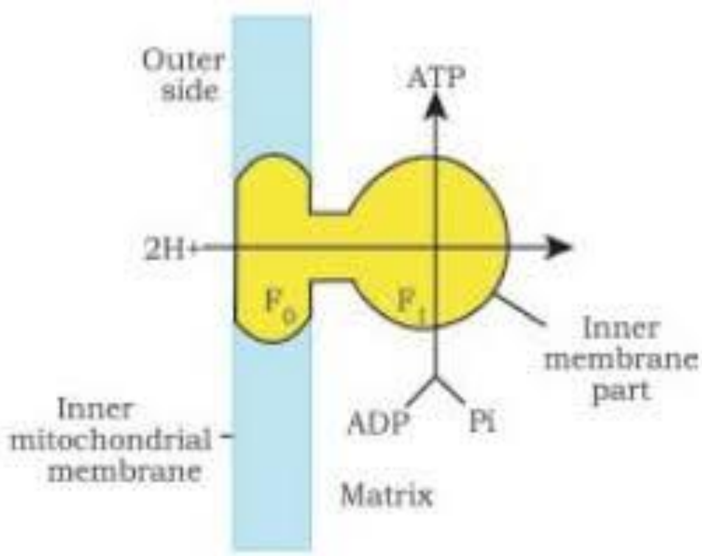
Chemiosmosis requires a membrane, a proton pump, a proton gradient and ATPase enzyme.

The channel of the F0 of the ATPase allows the diffusion of H^+ back across the thylakoid membrane. As a result, enough energy is released.

This energy activates ATPase.

ATPase catalyses ATP synthesis from ADP.

This ATP is used immediately in the dark reaction taking place in the stroma. As a result, sugar synthesis takes place by CO2 fixation.



13.7 Where are ATP and NADPH used?

Biosynthetic Phase:

Alternative names are **Calvin cycle, C3 cycle, Photosynthetic Carbon Reduction cycle, and Reductive pentose pathway.**

C3 cycle comes under dark reaction, as no direct light is required for the process to be carried out.

Calvin presented these reactions in a cyclic manner and it is thus called Calvin cycle.

A three carbon compound called Phosphoglyceric acid (PGA) is the first stable compound produced during Calvin cycle. Hence this cycle is also called as C3 cycle.

Calvin used *Chlorella pyrenoidosa* as the experimental organism. *Chlorella* is a unicellular green alga. This alga contains cup shaped chloroplast which performs photosynthesis similar to the higher plants. He used radioactive carbon dioxide containing radioactive isotope of carbon (^{14} C).He also used chromatography and autoradiography in his experiment.

ATP and NADPH produced during light reaction in the grana of the chloroplast are the essential requirements for the assimilation of CO_2 to carbohydrates.

All the necessary enzymes of CO_2 assimilation are localized in the stroma.

C3 pathway or dark reaction takes place in the **stroma of the chloroplast**.

13.7.1 The Primary Acceptor of CO2:

The primary CO2 acceptor is the 5 carbon compound RuBP.

13.7.2 The Calvin Cycle:

Calvin cycle is divided into 3 distinct stages.

- **Carboxylation**

- **Reduction**
- **Regeneration.**

1. Carboxylation-During which CO_2 combines with RuBP.

2. Reduction- During which carbohydrate is formed at the expense of the photo chemically made ATP and NADPH.

3. Regeneration- During which the CO_2 acceptor (RuBP) is formed again so that the cycle continues.

Carboxylation: The CO_2 fixation into a stable intermediate is called carboxylation.

The 5 carbon compound Ribulose bisphosphate (RuBP) present accept CO_2.

6 Molecules of RuBP combines with 6 molecules of CO2 to produce 6 molecules of 6 carbon compound.

Carbon compound formed are unstable. These 6 molecules of 6 carbon compound are immediately broken down into 12 molecules of 3 phosphoglyceric acid (PGA) in the presence of water.

The PGA is a 3 carbon compound and it is the first stable compound produced during photosynthesis.

The carboxylation reaction is catalysed by an enzyme called **RuBisCo (RuBP carboxylase)**.

RuBisCo also possesses oxygenation activity and hence abbreviated **as RuBisCo (RuBP carboxylase-oxygenase).**The oxygenation activity of the enzyme allows to compete with CO2 for combining with RuBP (Photorespiration).

Reduction: The process of addition of Hydrogen is called reduction.

PGA is reduced into glyceraldehydes phosphate by utilizing assimilatory powers, ATP and NADPH produced in light reaction. Hydrogen from NADPH is added in this reaction.

PGAL is a 3 carbon sugar (triose sugar). The ADP and $NADP^+$ regenerated are used again for further light reaction. This step is obviously a reversal of reaction steps of glycolysis. In this case, the reducing power is obtained from NADPH rather than NADH.

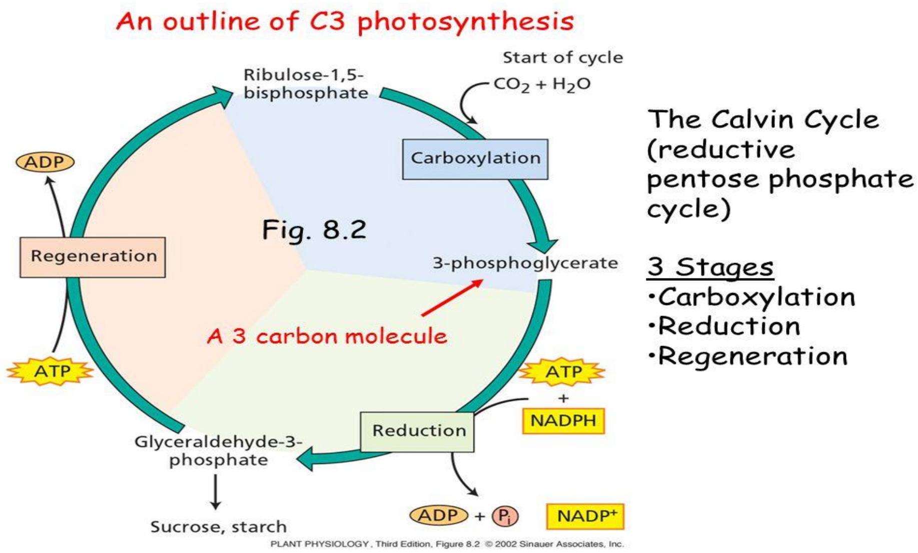
The 3 carbon molecule (PGAL) formed in the reduction reaction of Calvin cycle are also called triose phosphates. These triose phosphates (PGAL) act as precursors for the synthesis of sucrose and starch.

Regeneration: Of the 12 molecules of glyceraldehydes phosphate (PGAL) formed in the reduction stage, 10 molecules are obtained with 6 ATP molecules through a complex series of reactions regenerate Ribulose bisphosphate (RuBP).

The intermediate compounds such as **Erythrose mono phosphate, Xylulose mono phosphate, Sedoheptulose mono phosphate, Ribose mono phosphate and Ribulose mono phosphate are produced in this reaction.** The 6ATP used here also formed from the photochemical reactions. The regenerated RuBP is used to accept CO2 again. For every 6 molecules of CO2 that enters the Calvin cycle, the **net output is 2 molecules of PGAL. 6 turns of Calvin cycle are required to produce one molecule of glucose.**

$6RUBP + 6C0_2 + 18ATP + 12NADPH2 \longrightarrow 6RUBP + C_6H_{12}O_6 + 18ADP + 18Pi + 12NADP + 6H_20$.

The C3 cycle requires 18 ATP for the synthesis of one molecule of glucose. But of the 18 ATP, 6ATP molecules are used in the regeneration of RuBP after the formation of one molecule of glucose. In the Calvin cycle, ADP and $NADP^+$ required for light reaction are regenerated.



13.8 The C4 Pathway:

Also known as Hatch and Slack Pathway or Di carboxylic acid cycle or CO_2 concentration mechanism.

Kortschak and Hatch first observed that 4C, Oxalo Acetic Acid (OAA) is formed in sugarcane leaves during dark reaction.

A pathway for dark reactions in sugarcane and maize leaves was proposed by **Hatch and Slack**.

It is the CO_2 fixation in tropical plants like Maize, Sugarcane, Sorghum, Pearl millet, Amaranthus, etc.

Hatch and Slack reported that first formed acid is a 4 carbon compound called Oxaloacetic acid.

It showed a special leaf anatomy called **Kranz anatomy.**

Green bundle sheath cells present around the vascular bundles.

Two types of chloroplast (dimorphism) are present in the leaf cells.

In mesophyll cells, chloroplasts are small and with grana while chloroplast of bundle sheath cells are larger without grana.

PEPCase (Phospho enol pyruvate carboxylase) enzyme is present in the mesophyll cells while RuBisCo present in the bundle sheath cells.

In the C4 plants, C3 cycle occurs in bundle sheath cells, while C4 cycle occurs in mesophyll cells.

CO_2 acceptor in C4 is phosphoenolpyruvate which is a 3 carbon compound.

First carboxylation in C4 cycle is catalysed by PEPCase in the cytoplasm of mesophyll cells.

The second or final carboxylation takes place in bundle sheath cells through the C3 cycle.

30 ATP molecules are needed for the production of one glucose molecule in C4 plants.

The enzyme pyruvate phosphate dikinase (PPDK) converts pyruvate to PEP by converting an ATP to AMP. This regeneration of PEP helps C4 plants to increase the efficiency of CO2 fixation.

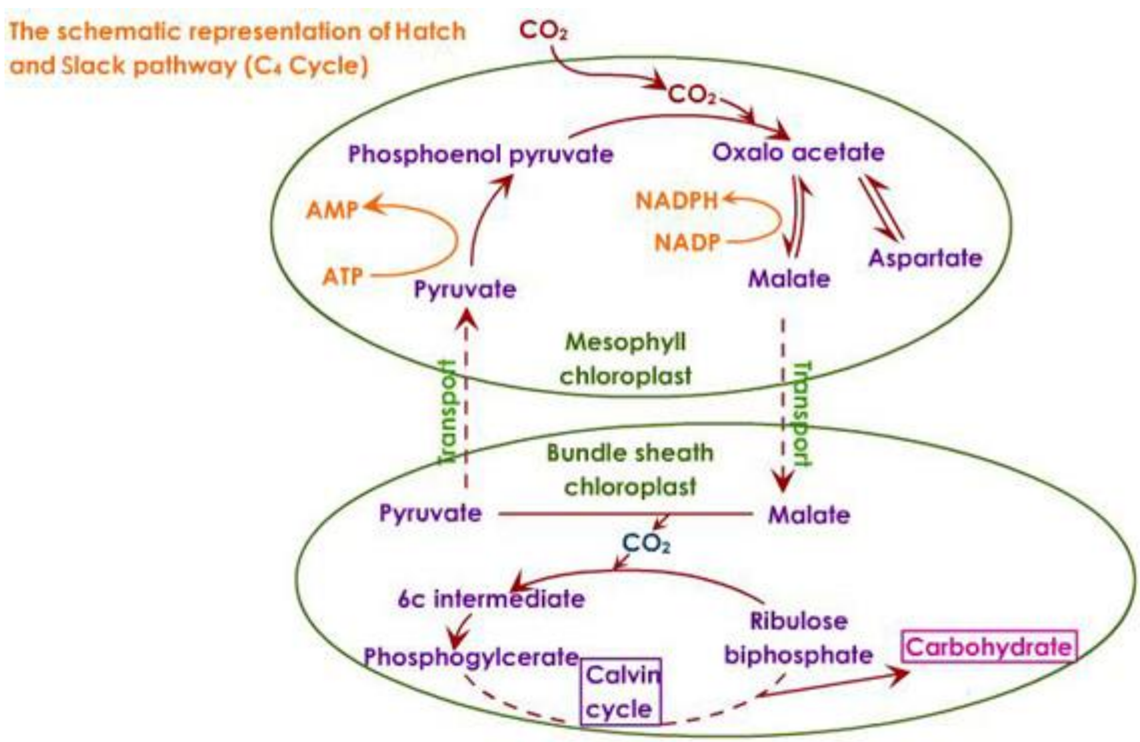
The pathway begins with the conversion of pyruvate into phosphoenol pyruvate by the enzyme pyruvate orthophosphate dikinase.

Then the fixation of CO2 into oxaloacetate by the enzyme PEP carboxylase. Both these reactions takes place in the mesophyll cells.

OAA is converted into malate which is transported into the bundle sheath cells.

Decarboxylation of Malate produce CO2 and pyruvate.

The CO2 now enters the Calvin cycle and pyruvate is transported into the mesophyll cells.



Advantages- No photorespiration, more efficient in picking CO_2 because PEP have more affinity to CO_2.

Effect of water stress is minimized in C4 plants. As bundle sheath cells lie close to the surface of water supply.

Tolerate stress because of organic acids.

C4 plants have strategies for minimizing water loss for fixation of same amount of CO_2.

C4 plants are twice efficient as C3 plants for the same amount of CO2 fixation.

CAM pathway or Crassulacean acid metabolism or Dark acidification:

First reported in ***Bryophyllum*** **a member of Crassulaceae.**

CAM is a kind of adaptation in succulents like *Opuntia*, Agave, Pine apple, Sedum, *Kalanchoe*, *Kleinia* etc.

Phosphoenol pyruvate is the primary acceptor of CO_2 and oxalo acetic acid is the first product.

In CAM plants stomata are of **scotoactive type (open at night).**

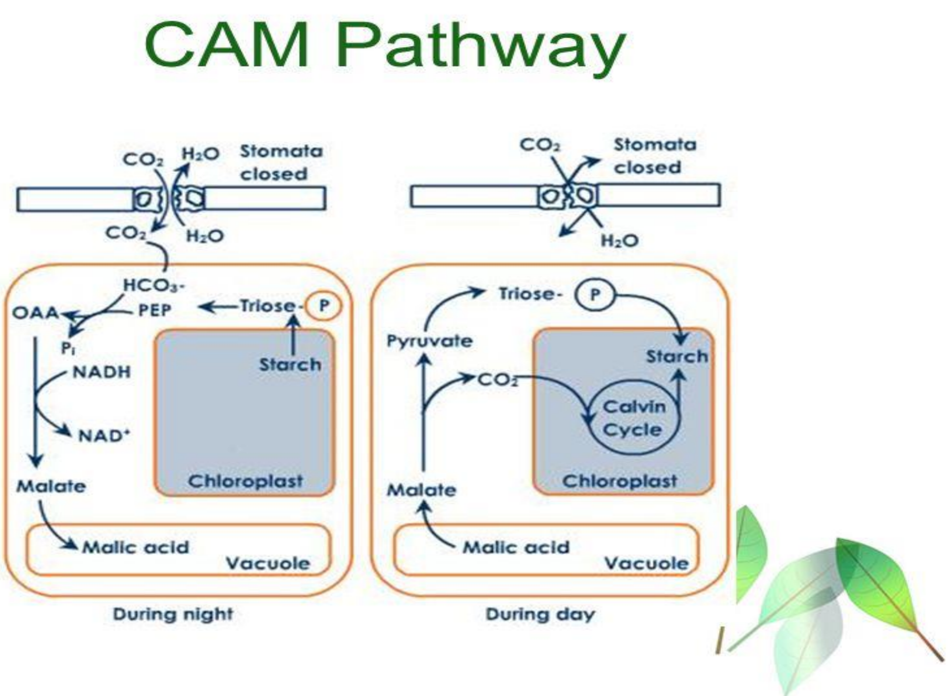
Organic acids are produced during night and they are broken down during the day and final CO_2 fixation occurs during the day time.

PEPCase induces carboxylation during night.

PEP carboxylase and RuBisCo are present in the mesophyll cells.

30ATP needed for the synthesis of 1 molecule of glucose and no kranz anatmy is seen.

The CAM plants leave the stomata closed during the day time and highly reduces the water loss during the day time.



13.9 Photorespiration:

Also known as **photosynthetic carbon oxidation cycle or C2 cycle or Glycolate metabolism.**

It is the light dependent utilization of oxygen and reduce CO_2 by photosynthetic organs.

It occurs at high temperature and high Oxygen.

Under this condition the affinity of RuBP towards oxygen increases and CO_2 decreases.

Photorespiration does not produce energy and it may reduce photosynthesis by up to 50%.

But in C4 plants it is overcome by Kranz anatomy.

Here instead of PGA, phosphoglycolate (PA) is produced and is recycled to produce PGA through photorespiratory pathway.

It occurs in chloroplast, Peroxisomes and mitochondria.

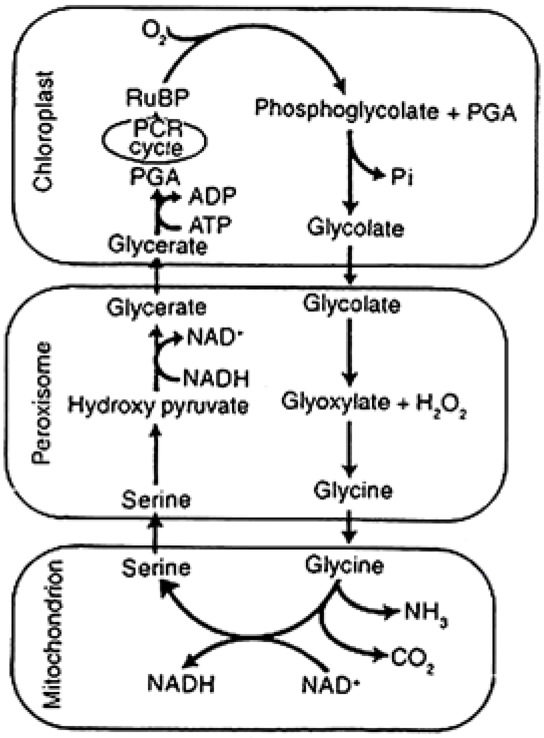


Fig. 5.10. Photorespiration.

13.10 Factors affecting photosynthesis:

External factors:

- Availability of sunlight,
- CO2 concentration
- Temperature
- Water.

F.F Blackman proposed the law of limiting factor in 1905.

It states that if a chemical process is affected by more than one factor, then its rate will be determined by the factor which is nearest to its minimal value: it is the factor which directly affects the process if its quantity is changed. Among all the factors of a biochemical process, the slowest or the smallest factor affects the total rate of the process. This smallest factor is called the limiting factor.

13.10.1 Light: There is a linear relationship between light intensity and rate of photosynthesis at low light intensity. At extreme light **photo oxidation of chlorophyll molecules** takes place which decreases the rate of photosynthesis.

The intensity of light at which the rate of photosynthesis becomes equal to the rate of respiration is called the compensation point. Beyond saturation, photosynthesis declines due to **solarisation.**

Chloroplast align parallel to the cell wall for absorbing maximum light and align to the cell wall for absorbing minimum light.

Light intensity, light quality and duration of exposure of light influence photosynthesis.

Light between the wave length of 400-700nm in the visible spectrum is the most effective for photosynthesis. This light is called photosynthetically active radiation (PAR).

The rate of photosynthesis increases with the increase in the light intensity. At higher light intensity the rate of photosynthesis decreases.

Light quality-The maximum rate of photosynthesis is in red light. The rate of photosynthesis in plants growing under canopy will be decreased since green light is inert for photosynthesis.

Longer duration of exposure to light period helps photosynthesis.

If the plants get 10 to 12 hours of light per day it helps the plants to carry out photosynthesis more efficiently.

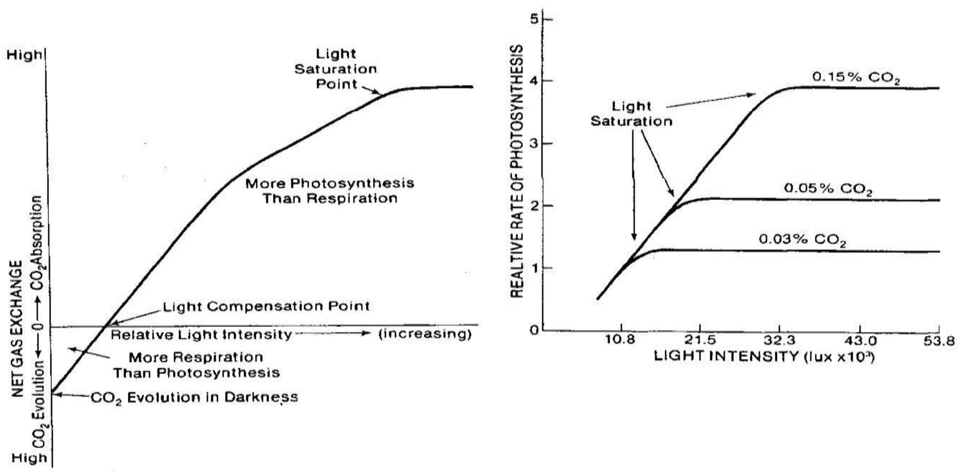


Figure 11.7 (A). Effect of light on rate of photosynthesis and (B) light saturation at different concentrations of carbon dioxide at a constant temperature (25°C)

13.10.2 Carbon dioxide concentration -It is the major limiting factor. The percentage of CO_2 in atmosphere is 0.03% and in water is 0.3%. So algae are more productive.

Photosynthesis in C4 plant is less limited by atmospheric CO_2 because the fixation of CO_2 is mediated through PEPCase.

Productivity of C4 plants does not increase when concentration of CO_2 increases because present level of atmospheric CO_2 is not generally a limiting factor for C4 plants.

High CO_2 compensation point in C3 plants but in C4 plants it is low.

Very high Concentration of CO2 stimulate abscissic acid which leads to the closure of stomata and reduces the CO_2 uptake. Hence the photosynthetic rate is decreased.

13.10.3 Temperature: Dark reaction being enzymatic, it is temperature controlled. Optimum temperature in C3 plants is 20-25 and in C4 30-45 degree centigrade.

Enzymes are inactive at high temperature as they get denatured. At low temperature also the enzymes are inactive.

13.10.4 Water: Less than 1% of the water absorbed by the land plant is utilized for photosynthesis. Availability of water in soil has a prominent effect on plant photosynthesis.

If soil water becomes a limiting factor, plants undergo water stress. Under the conditions of water stress, the rate of photosynthesis decreases.

Internal factors:

1. **The number, size , age and orientation of leaves, mesophyll cells and chloroplast**

2. Internal CO_2 concentration

3. The amount of chlorophyll are the important internal factors which affect the rate of photosynthesis.

The Number, size , age and orientation of leaves, mesophyll cells and chloroplast:

As the leaves develop, the capacity of photosynthesis increases and reaches the maximum due to the increase in the metabolic activities of the cells. Then onwards there is a decline in the rate of photosynthesis with age.

If leaf turns yellow due to ageing (senescence), loss of chlorophyll occurs. In aged leaf the enzymes become inactivated which affect the rate of photosynthesis.

Generally leaves are either arranged vertically or at right angle to sunlight. In shade plants, leaves are arranged horizontally to receive maximum sunlight.

Internal CO_2 concentration: Increase in the rate of CO_2 uptake increases the internal CO_2 concentration in both C3 and C4 species.

High light intensity induces the opening of stoma. When stoma opens CO_2 uptake increases.

Increase in diffusion of CO_2 into the leaf increases the internal CO_2 concentration. This increase in internal CO_2 increases the rate of photosynthesis in both C3 plants and C4 plants. C4 plants have developed a system of concentrating CO_2 in their bundle sheath cells.

Amount of chlorophyll: Chlorophyll is necessary for photosynthesis. The chlorophyll content of the leaves never becomes a limiting factor in photosynthesis. For example, the sun plants contain less chlorophyll in their leaves than those of shade plants. But the sun plants show a high rate of photosynthesis in bright light than the shade plants.

Fast Revision Track:

The process by which green plants prepare their food using solar energy is called photosynthesis.

Chlorophyll is the main photosynthetic pigments.

Carotenoids are the coloured pigments.

Quantosomes are the unit of photosynthesis.

Absorption spectrum is the graph obtained by plotting absorption vs wavelength for a particular pigment.

Action spectrum is the graph plotted showing the effectiveness of wavelength of light in stimulating the process.

Photosystems are the functional and structural units consisting of protein complexes involved in photosynthesis.

They are located on the thylakoid membranes

Two types of photosystem-PS1 and PS II

C3 cycle in normal plants

C4 cycle is plants with Kranz anatomy.

CAM pathway in plants whose stomata opens during night.

Photorespiration is a waste in plants as no glucose or ATP or NADPH produced.

Photorespiration is the pathway to recycle phosphoglycolate.

Light, CO_2 concentration, Temperature, Water, leaf anatomy, Chlorophyll etc are the factors affecting photosynthesis.