3

Photosynthesis

All animals including human beings depend upon plants for their food. All green plants carry out photosynthesis. Various kinds of algae, several bacteria and all higher green plants synthesize their own food through this process. During this process light energy of sun is fixed as a chemical energy in food, which is used by all other organisms. Thus the energy requirement of the entire living world is fulfilled through photosynthesis. The fossil fuel from which we obtain energy is also a product of photosynthesis in the past. During photosynthesis CO_2 from the atmosphere is consumed and at the end of this process O_2 is released into the atmosphere as a by-product. As energy is fixed during this process, it is considered as an endergonic process.

What do you know ?

Let us see what we know about photosynthesis. Some simple experiments you might have performed in earlier classes which have shown that chlorophyll, light and CO_2 are required for photosynthesis to occur.

The two leaves experiment showing formation of starch might have carried out by you in which one leaf was covered by black paper and other was exposed to light. On testing these leaves for starch it was clear that photosynthesis took place only in the green part of the leaf which was exposed to sun light.

Another experiment which you may have carried out is the half leaf experiment where a part of leaf is inserted in a test tube having KOH soaked cotton (which absorbs CO_2), while the other half is exposed to air. This setup is then placed in sunlight for some time. On testing for the starch it was found that only the exposed part of leaf gave positive test for starch. This indicates that CO_2 is required for photosynthesis.

Early Experiments

The study of the process of photosynthesis dates back to some 300 years.

Joseph Priestley (1733 – 1804) : In 1770 performed a series of experiments and showed that plants obtain CO_2 from the atmosphere and release O_2 in the atmosphere.

Jan Ingenhousz (1730 – 1799) : Performed an experiment on aquatic plant and showed that in bright sunlight, small bubbles were formed around the green parts of the plant while in the dark they did not. He identified these bubbles to be of oxygen. He concluded that only those organs of plants which possess chlorophyll release O_2 and that too only in presence of light.

Julius Von Sachs (1854) : He showed that green substance (chlorophyll) in plants is located in special bodies (chloroplasts) of plant cell. This green substance produces glucose which is usually stored in the form of starch.

By the middle of the nineteenth century it became established that plants prepare food using CO_2 and H_2O in presence of light and release O_2 in the atmosphere. The empirical equation representing the total process of photosynthesis for oxygen evolving organisms can be explained as below :

$$CO_2 + H_2O \xrightarrow{\text{Light}} [CH_2O] + O_2$$

Where $[CH_2O]$ represented a carbohydrate.

Cornelius van Niel (1897 – 1985) : Who, based on his studies on purple and green bacteria, demonstrated that photosynthesis is essentially a light dependent reaction in which hydrogen from a suitable oxidisable compound reduces carbon dioxide to carbohydrates. Niel put up a simple equation for plant as follow :

$$2\ H_2O + CO_2 \xrightarrow{\text{Light}} O_2 + CH_2O + H_2O$$

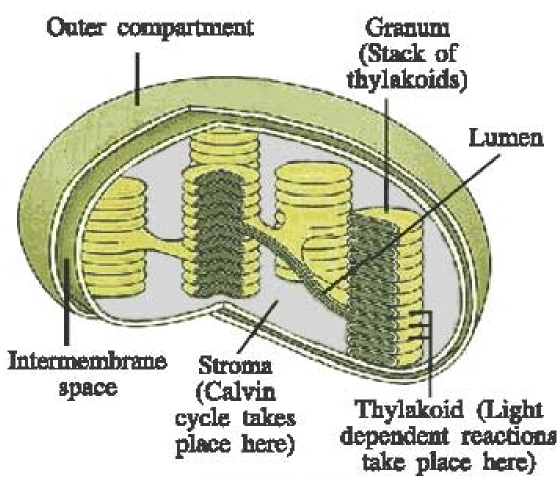
Later, another scientist **Robert Hill** demonstrated that the O_2 released into atmosphere comes from water. Thus the equation was modified as under :

$$6CO_2 + 12\ H_2O \xrightarrow{\text{Light}} C_6H_{12}O_6 + 6H_2O + 6O_2$$

Where does photosynthesis takes place ?

The process of photosynthesis takes place only in the green organs of the plants. Amongst these, the leaves are the main organs. Even in a leaf this process occurs in the chlorenchyma of mesophyll. The cells of this tissue possess organelles called chloroplasts. The chloroplasts are arranged in the peripheral region of the cell, which facilitates the diffusion of gases.

We have earlier studied the structure of chloroplast. Within the chloroplast, there is the membranous system consisting of grana and the fluid stroma. Each granum is made up of flat, lamellar structures called thlakoids which are arranged like a stack pile of coins. Thylakoids contain chlorophyll pigments. A clear division of labour can be seen in chloroplast. The membrane system is responsible for trapping the light energy and synthesis of ATP and NADPH. This is called light reaction. In stroma enzymatic reactions incorporate CO_2 into the plant leading to synthesis of sugar. Since it is not light driven process, it is known as dark reaction.



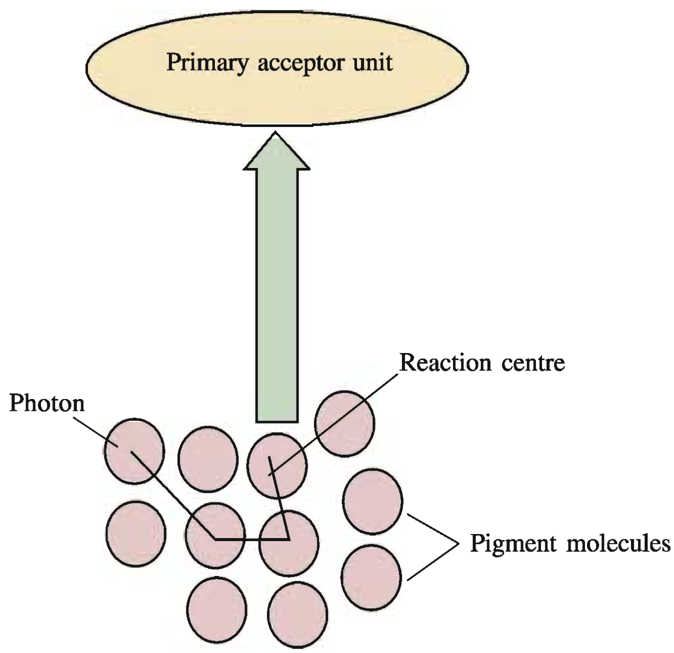
Chloroplast

How many pigments are involved in photosynthesis

Chromatographic separation of leaf pigments shows that the color that we see in leaves is not due to a single pigment but due to four pigments; chlorophyll-a, chlorophyll-b, xanthophyll and carotenoids, Chlorophyll-a and chlorophyll-b are green pigments, xanthophylls are yellow and carotenoids are yellow to orange pigments. These pigments are concerned with absorption of light energy. They absorb light at specific wavelength and obtain energy from them. This energy is first converted into the energy of electrons and later into chemical energy. Chlorophyll-a molecules are the main reactants in this process. The other kinds of pigments direct and focus the energy absorbed by them towards chlorophyll-a and hence, they are known as accessory pigments. Thus chlorophyll-a molecules act as reaction centres.

What is light reaction ?

Presence of light is inevitable for light reaction. Hence, this reaction is also known as photochemical phase. It takes place in the grana regions of chloroplast. This reaction involves absorption of light, photolysis of water, release of oxygen and formation of ATP and $NADPH_2$. The photosynthetic pigments, mentioned above, are organized into two photochemical Light Harvesting Complexes (LHC) like the photosystem-I (PS-I) and photosystem-II (PS-II). In the first kind of pigment system, the chlorophyll-a molecules at the reaction centre are stimulated by the wavelength of 700 nm and hence, it is also called P_{700}. In the other pigment system the chlorophyll-a molecules at the reaction centre are stimulated by the wavelength of 680 nm and hence, it is called P_{680}. Each pigment system is made up of around 250 to 400 molecules (except one molecule of chlorophyll-a) forming a light harvesting system called antennae.The single chlorophyll-a molecule forms the reaction centre.



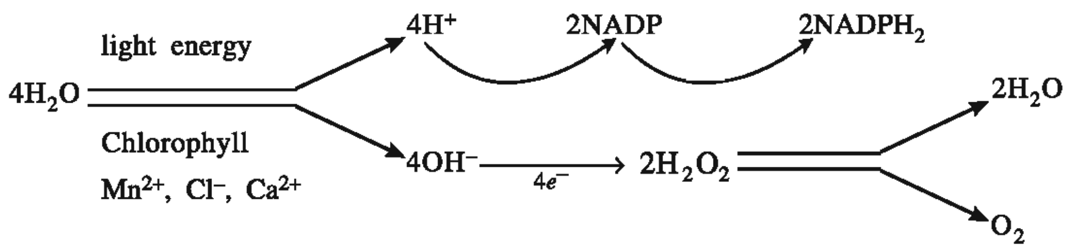
Light Harvesting Complex (LHC)

The Electron Transport System

In electron transport system, the electrons which are released from reaction centre transport in two ways : (1) Cyclic and (2) Non cyclic ways. Before going to study the transport of electrons we will see the splitting of water molecules during light reaction.

Splitting of water molecules : The splitting of water molecule using energy of light is known as photolysis of water. During this process 4 molecules of water split simultaneously. Thus $4H^+$ and

$4OH^-$ are released. These $4H^+$ are accepted by two molecules of hydrogen acceptor-NADP . Thus 2 molecules of NADP are converted into 2 molecules of $NADPH_2$. The 4 OH^- lose their 4 e^- and release 2 molecules of H_2O and 1 molecule of O_2. The entire process can be presented as under :

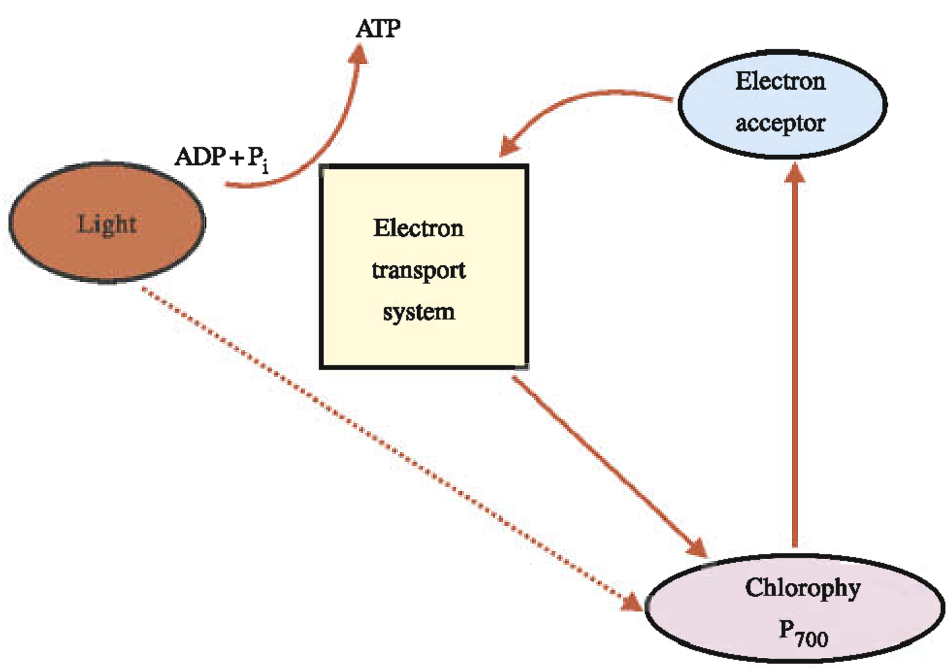


Mn^{2+}, Cl^- and Ca^{2+} play an important role in this process. The light energy required for photolysis of water is absorbed by PS-II. 2 NADP, $2H^+$ obtain $4e^-$ from PS-I and get converted into $2NADPH_2$. This $NADPH_2$ is later used in biosynthetic phase for reduction of CO_2.

Photophosphorylation : During this process ADP is phosphorylated and ATP is formed. Thus light energy gets converted into chemical energy. Photophosphorylation occurs in two ways : Cyclic Photophosphorylation and Noncyclic Photophosphorylation.

(1) Cyclic Photophosphorylation : In this process only PS-I participates. PS-I is stimulated by absorbing 4 photons from light of wavelength 700 nm. As a result 4 energy rich electrons are set free from the reaction centre of PS-I. These electrons are picked up by an electron acceptor which passes them to an electron transport system consisting of cytochromes.

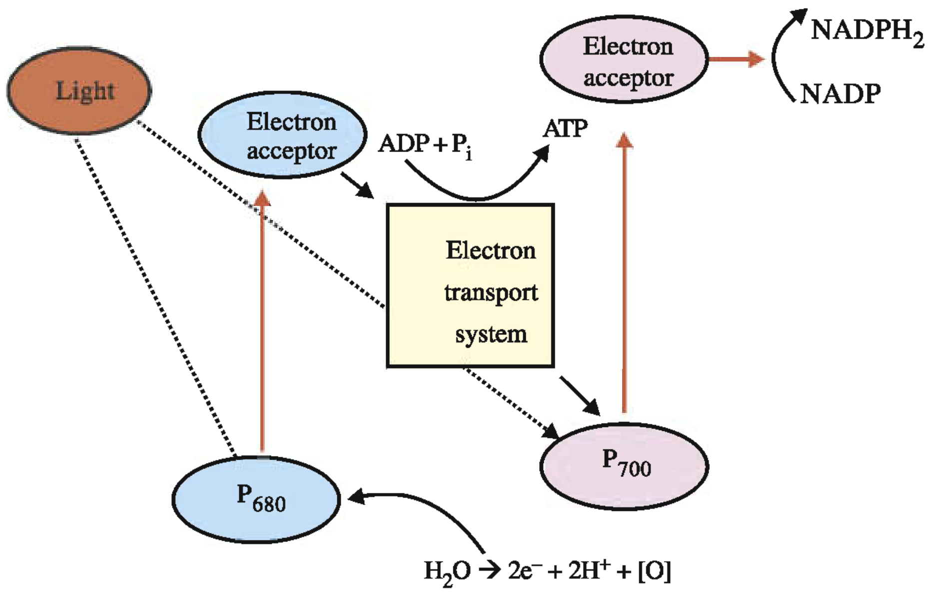
During this course of electron transport, energy is released from the electrons which is utilized for the synthesis of 2 molecules of ATP. As the electrons return to their original source, such a transport of electrons is called cyclic electron transport.



Cyclic Photophosphorylation

(2) Noncyclic photophosphorylation : In this process both PS-I and PS-II take part, in which 4 photons of sunlight of 680 nm wavelength stimulate PS-II where by $4e^-$ are released from reaction centre. The $4e^-$ released are accepted by various electron acceptors and finally enter into PS-I instead of returning to PS-II. Thus chlorophyll –a molecules at the reaction centre of PS-I receive $4e^-$ from PS-II. During this transport of electrons energy is released at various stages which is stored in phosphorylation of ADP to ATP. Simultaneously the $4e^-$ released by reaction centre of PS-I after receiving red light of wavelength 700 nm, neither go to PS-I nor to PS-II but are first accepted by electron acceptor and then utilized for the reduction of NADP.

As the electrons released in various ways do not return to their original donors, such an electron transport is called noncyclic electron transport.



Noncyclic photophosphorylation

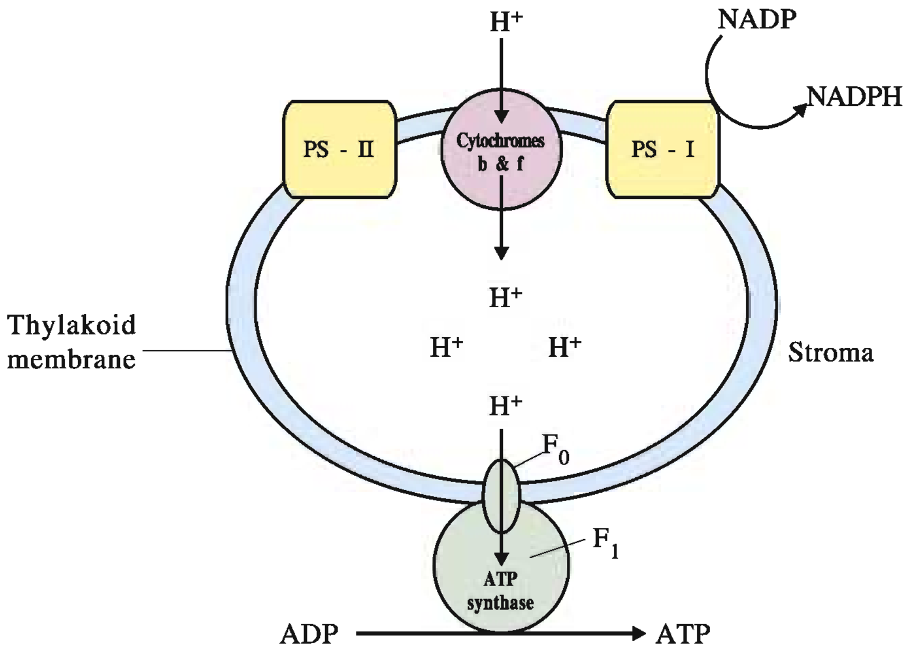
Chemiosmotic Hypothesis : The chemiosmotic hypothesis has been put forward to understand the synthesis of ATP in chloroplast. ATP synthesis is linked to development of proton gradient across the membrane of thylakoids. The proton accumulation takes place in the lumen of thylakoid. As the splitting of water molecule takes place inside the thylakoid, the protons or hydrogen ions that are produced, accumulate within the lumen of thylakoid. On the other side the reduction of NADP takes place in the stroma, outside the membrane. For this reduction protons are required and the protons which are present in the stroma are used up. Hence, within the chloroplast, protons in the stroma decreases in number, while in the lumen of thylakoid there is accumulation of protons. This creates a proton gradient across the thylakoid membrane.

What is the role of proton gradient ? Infect it is the breakdown of proton gradient which leads to release of energy. The gradient is brokendown due to the movement of protons across the membrane to the stroma through the transmembrane channel of the Fo of the ATPase. The ATPase enzyme consists of two parts :

(1) Fo - which is embedded in the membrane and forms a transmembrane channel through which diffusion of protons across the membrane takes place.

(2) F_1 - which protrudes on the outer surface of the thylakoid membrane on the side that faces stroma.

The breakdown of the gradient provides enough energy to cause a conformational change in the F_1 particle of ATPase, which makes the enzyme to synthesise several molecules of energy packed ATP. The ATP produced will be used immediately, along with NADPH, in the biosynthetic phase taking place in the stroma.



ATP synthesis through chemiosmosis

Where are the ATP and NADPH used ?

We have studied that during light reaction ATP, NADPH and O_2 are produced. O_2 diffuses out of the chloroplast while ATP and NADPH are used in the process of dark reaction or biosynthetic phase. Thus biosynthetic phase does not depend on light but it depend on the products of light reaction.

Let us now see how the ATP and NADPH are used in the biosynthetic phase. As we know that in biosynthetic phase H_2O combines with CO_2 to produce sugar. It was of interest to scientists to find out how this reaction proceeded or what is the first product formed when CO_2 is fixed. Melvin Calvin by using radioactive C^{14} in algal photosynthesis discovered that the first CO_2 fixation product was a 3-carbon organic acid i.e. 3-phosphoglyceric acid (PGA). He also studied complete biosynthetic pathway and hence it is also called as Calvin cycle.

Later on scientists also tried to know whether all plants have PGA as the first product of CO_2 fixation. Experiments conducted over a wide range of plants led to the discovery of another group of plants where the first product of CO_2 fixation was 4-carbon compound i.e. oxaloacetic acid (OAA). Since then CO_2 fixation during photosynthesis was said to be of two types:

(1) Those plants in which the first product of CO_2 fixation is a C_3 acid (PGA) i.e. C_3 pathway and

(2) Those plants in which the first product of CO_2 fixation is C_4 acid (OAA) i.e. C_4 pathway .

The primary acceptor of CO_2 : The scientists took a long time and conducted many experiments to known the primary acceptor of CO_2. Later on it was proved that the 5-carbon ketose sugar i.e ribulose biphosphate (RuBP) was the first acceptor molecule.

The Calvin cycle : Calvin and his co-workers worked out the whole pathway and showed that the pathway operated in cyclic manner. The entire Calvin cycle can be described under the following three steps :

(1) Carboxylation : Carboxylation is the fixation of CO_2 into a stable organic intermediate. First of all the CO_2 obtained from the atmosphere, combines with 5-C pentose sugar ribulose biphosphate obtained from the stroma and a 6-C unstable complex is formed which then splits into two molecules of a 3-C compound called phosphoglyceric acid (PGA). This reaction is catalysed by the enzyme RuBP carboxylase. This phase is called carboxylation phase.

(2) Reduction : A series of reactions are involved in the formation of glucose. The steps involved utilization of 2 molecules of ATP for phosphorylation and 2 molecules of NADPH for reduction per CO_2 molecule fixed. For the formation of one molecule of glucose fixation of six molecules of CO_2 and six turns of the cycle are required.

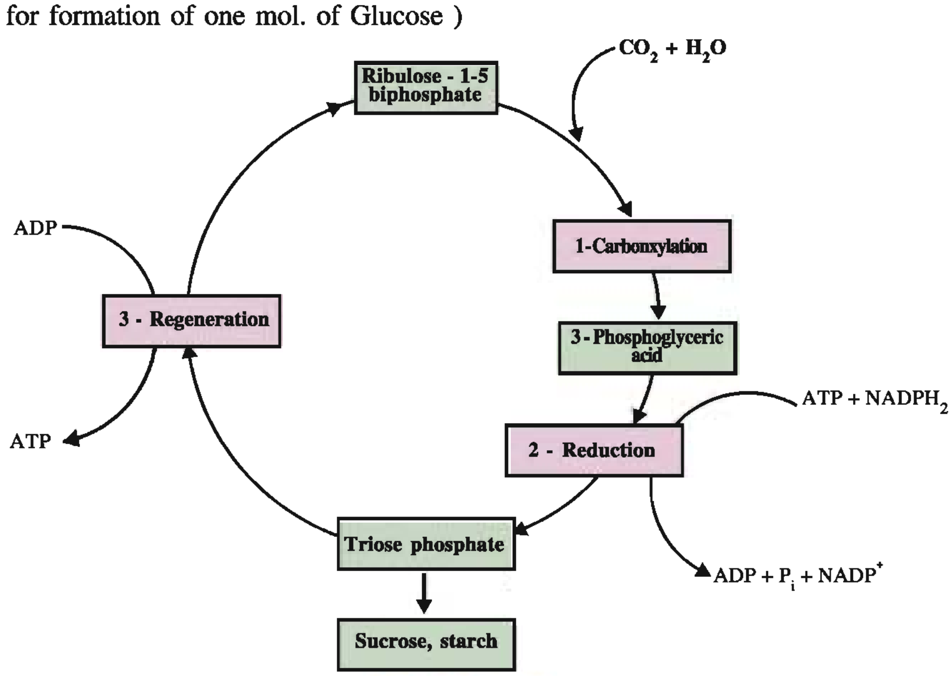
(3) Regeneration : Regeneration of RuBP is essential if the cycle is to be continued without break. Hence one ATP is also required for phosphorylation to form RuBP.

In this way for every CO_2 molecule entering the Calvin cycle, 3 molecules of ATP and 2 molecules of NADPH are required. As you know that for the formation of one molecule of glucose 6 turns of the cycle are required, how many ATP and NADPH molecules will be required to make one molecule of glucose ?

For one CO_2 molecule, 3 ATP and 2 NADPH are required so

For six CO_2 molecules, 18 ATP and 12 NADPH are required.

(i.e. for formation of one mol. of Glucose)



The Calvin cycle

The C_4 pathway

This pathway is also called Hatch-Slack pathway. C_4 pathway is generally observed in the monocot plants which grow in the tropical regions. It is very clearly observed in the leaves of sugarcane.

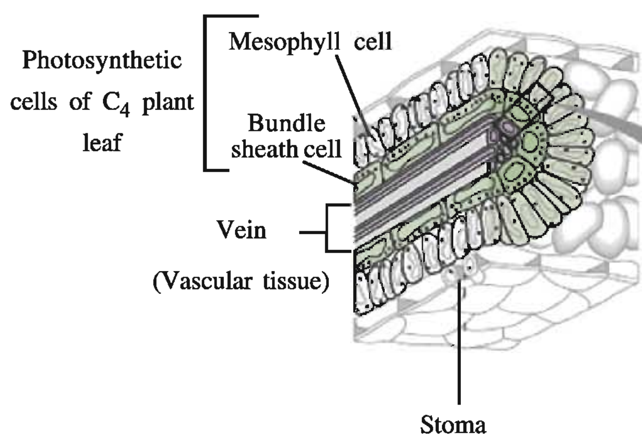
As earlier we have studied that C_3 path operates in the mesophyll cells, light phase and CO_2 fixation, both occur in the cells of mesophyll.

The C_4 pathway operates in two kinds of photosynthetic cells – mesophyll cells and bundle sheath cells. The bundle sheath cells are arranged surrounding the vascular bundles. Such an arrangement is called Kranz anatomy. The chloroplasts in mesophyll cells exhibit grana organization. The chloroplasts in bundle sheath cells do not show grana organization. They do possess thylakoids but they are not arranged into grana. These two kinds of cells perform two different types of reactions. The light reaction takes place in mesophyll cells while dark reaction occurs in bundle sheath cells. The arrangement prevents the O_2, evolved during light reaction, from entering the bundle sheath cells. Thus there is no possibility of photorespiration.

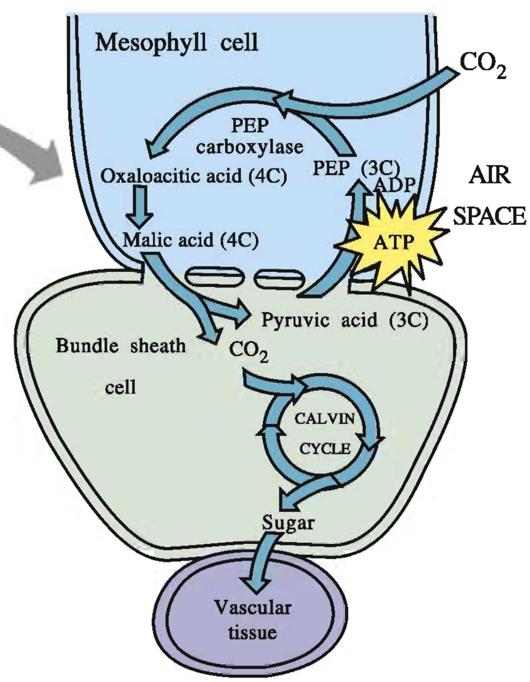
In C_4 pathway, atmospheric CO_2 first diffuses into mesophyll. This CO_2 reacts with a 3-C substance called phosphoenol pyruvic acid and forms a 4-C oxalo-acetic acid. As the first product is a 4-C molecule, this path is called C_4 path.

Now, oxalo-acetic acid is converted into malic acid which is thus formed is transported to the chloroplasts of bundle sheath cells. Here it is decarboxylated and one molecule of a 3-C pyrucic acid is formed and CO_2 is released. Pyruvic acid is transported back to chloroplast in mesophyll cells. Here it is converted to phosphoenol pyruvic acid. Thus the cycle continues.

Due to release of CO_2 in bundle sheath cells, the concentration of CO_2 goes on increasing. As the process of CO_2 fixation occurs in these cells also, more food is prepared through biosynthetic fixation. As there is no possibility of photorespiration, production of carbohydrates through C_4 path is more efficient than that through C_3 path.



C_4 Leaf anatomy



The C_4 Pathway

Table : Differences between C_3 and C_4 path

No.	Character	C_3 path	C_4 path
(1)	Type of cell	**One (mesophyll)**	**Two (Mesophyll and Bundle sheath cells)**
(2)	Kranz Anatomy	**Does not occur**	**occurs**
(3)	Chloroplast	**With grana**	**With and without grana**
(4)	First CO_2 acceptor	**RuBP**	**PEP**
(5)	First product	**PGA (C_3)**	**Oxalo acetic acid (C_4)**
(6)	Productivity	**Normal**	**High**

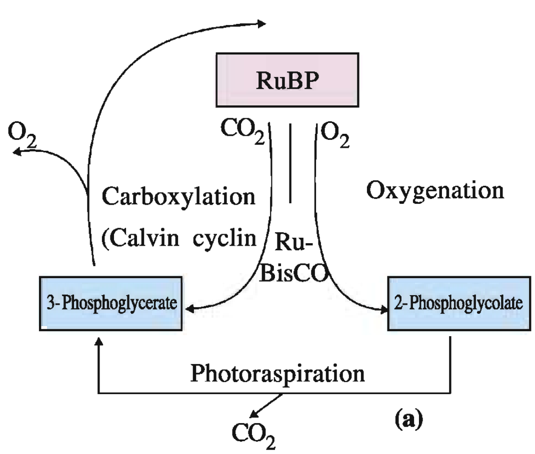
Photorespiration

We studied that in the biosynthetic phase of the photosynthesis, the atmospheric CO_2 combines with RuBP and forms two molecules of PGA. This carboxylation reaction is catalyses by an enzyme called Ribulose-bi-phosphate carboxylase (RuBisCO). This is the most abundant enzyme in the world and is characterized by the fact that its active site can bind to both CO_2 and O_2. Hence, it can also act as an oxygenase enzyme.

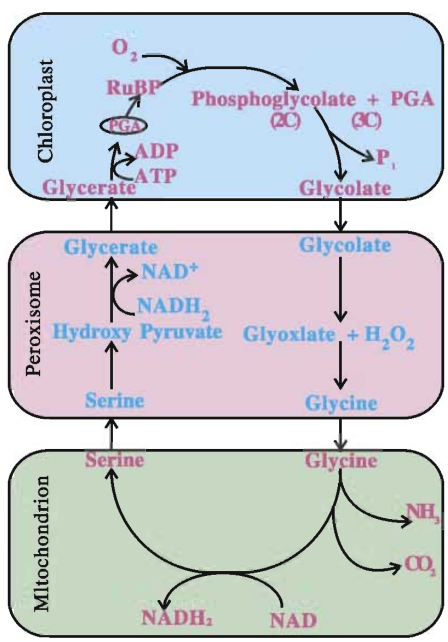
Photorespiration is a process of respiration which takes place in chloroplast in presence of light. In this process first of all RuBP is oxygenated in presence of O_2 forming one molecule of a 2-C phosphoglycolate and one molecule of a 3-C PGA. The PGA molecule is used in the Calvin cycle. Phosphogycolate is dephosphorylated forming glycolate. Glycolate diffuses out of chloroplast and enters the organelle called peroxisome. Here it is oxidized and becomes glyoxylate which is used in the synthesis of glycine.

Glycine now diffuses out of peroxisome and enters mitochondrion. Here 2 molecules of 2-C glycine unite and form one molecule of 3-C serine. During this one molecule of CO_2 is released.

Serine now diffuses out of mitochondrion and reenters into peroxisome. After some chemical reactions it is converted into glycerate. Glycerate diffuses out of peroxisome and enters chloroplast. Here it is phosphorylated to form PGA which enters the Calvin cycle.



(a)



b

(a) Role of RuBisCO in Calvin Cycle and Photorespiration
(b) Significance of Various Organelles in Photorespiration

One molecule of CO_2 which was released in the mitochondrion during formation of serine will have to be refixed. Thus, 75 % of carbon lost due to oxygenation of RuBP is recovered and 25% is wasted as one molecule of CO_2.

Under the condition of intense light and poor availability of CO_2, photorespiration plays a defensive role. With insufficient availability of CO_2 the light energy cannot be fully utilized and thus excess light can cause photooxidation and damage the plant. Photorespiration provides protection against this.

In C_3 plants some O_2 does bind to RuBisCO, and hence CO_2 fixation is decreased . In C_4 plants photorespiration does not occur. This is because they have a mechanism that increases the concentration of CO_2 at the enzyme site. This ensures that RuBisCO functions as carboxylase minimizing the oxygenase activity. This is the reason why productivity and yield are better in C_4 plants.

Factors affecting photosynthesis

The rate of photosynthesis is very important in determining the yields of plants including crop plants. Photosynthesis is under the influence of several factors, both internal and external. When several factors affect any (bio) chemical process, Blackman's (1905) Law of limiting factors comes into effect. This states the following:

"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." For example, despite of presence of green leaf, optimal light and CO_2 conditions, photosynthesis may not occur if temperature is very low. This leaf, if given the optimal temperature, will start photosynthesizing.

Light : Both, the intensity and quality of light influence photosynthesis. Normally as intensity of light increases, the rate of photosynthesis increases. However, at higher intensity it is not so. At high intensity of light, oxidation of chlorophyll occurs and it is decomposed. This is called photooxidation. Because of this the rate of the process drops.

The visible spectrum of light ranges from 400 nm to 700 nm. Plants can absorbed light from this range only. The rate increases in orange and red light. It decreases in green light.

CO_2 concentration : The concentration of CO_2 is very low in the atmosphere i.e 0.036 %. Increase in the concentration upto 0.05 % can cause an increase in CO_2 fixation rates. Beyond this the levels can become damaging over longer periods. The effect of CO_2 concentration beyond this level for longer periods is damaging. At high light intensity both, C_3 and C_4 plants show increase in the rates of photosynthesis. What is important to note is that C_4 plants show saturation at about 360 μlL^{-1} while C_3 responds to increased CO_2 concentration and saturation is seen only beyond 450 μlL^{-1}. Thus current availability of CO_2 levels is limiting to the C_3 plant.

Temperature : There are two phases in photosynthesis. There is no notable effect of temperature in the photochemical phase but as dark reaction or biosynthetic phase being enzymatic, temperature has a remarkable effect on it. The C_4 plants respond to higher temperatures and show higher rate of photosynthesis while C_3 plants have a much lower temperature optimum.

Water : The effect of water is remarkable. When availability of water is reduced, the plant experiences water stress. This has two effects – one is that the stomata are closed, as a result the amount of available CO_2 is reduced. Secondly, as water potential in leaves is lowered, they curl. Thus available leaf area is reduced for photosynthesis.

Summary

During photosynthesis light energy of sun is fixed as a chemical energy in food, which is used by all other organisms. The process of photosynthesis takes in the green organs of the plants. Amongst these, the leaves are the main organs. Even in a leaf this process occurs in the chlorenchyma of mesophyll. The cells of this tissue possess organelles called chloroplasts. The chloroplasts are arranged in the peripheral region of the cell. This facilitates the diffusion of gases. A clear division of labour can be seen in chloroplast. The membrane system is responsible for trapping the light energy and synthsis of ATP and $NADPH_2$. This is called light reaction. In stroma enzymatic reactions incorporate CO_2 into the plant leading to synthesis of sugar. Since it is not light driven process, it is known as dark reaction.

In electron transport system, the electrons which are released from reaction centre transport in two ways : (1) Cyclic and (2) Non cyclic ways. In the cyclic system electrons return to their original source and hence such a transport of electrons is called cyclic electron transport. While in non-cyclic system electrons released in various ways do not return to their original donours, such an electron transport is called non-cyclic electron transport.

The chemiosmotic hypothesis indicates that the breakdown of the proton gradient provides enough energy to cause a conformational change in the F_1 particle of ATPase, which makes the enzyme synthesise several molecules of energy packed ATP.

CO_2 fixation during photosynthesis occurs in two ways : (1) Those plants in which the first product of CO_2 fixation is a C_3 acid (PGA) i.e. C_3 pathway and (2) Those plants in which the first product of CO_2 fixation is C_4 acid (OAA) i.e. C_4 pathway.

Photorespiration is a process of respiration which takes place in chloroplast in presence of light. In this process first of all RuBP is oxygenated in presence of O_2 forming one molecule of a 2-C phosphoglycolate and one molecule of a 3-C PGA. In C_3 plants some O_2 does bind to RuBisCO, and hence CO_2 fixation is decreased. In C_4 plants photorespiration does not occur. This is because they have a mechanism that increases the concentration of CO_2 at the enzyme site. This ensures that RuBisCO functions as carboxylase minimizing the oxygenase activity. This is the reason why productivity and yield are better in C_4 plants.

The rate of photosynthesis is affected by the various factors like temperature, concentration of CO_2, light and water.

Exercise

1. Put a dark colour in a given circle for correct answer :

(1) Non-cyclic photophosphorylation is performed during

(a) Dark reaction ○ (b) Photochemical Phase ○

(c) (a) and (b) both ○ (d) None of the above ○

(2) Calvin cycle occurs in

(a) Cytoplasm ○ (b) Mitochondria ○

(c) Glyoxysomes ○ (d) Chloroplast ○

(3) Element essential for splitting of water is

(a) Nitrogen ○ (b) Oxygen ○

(c) Chlorine ○ (d) Carbon ○

(4) C_4 plants differ from C_3 plants with respect to

(a) First product ○

(b) Substrate which accepts carbon dioxide ○

(c) Number of ATP molecules consumed ○

(d) All the above ○

(5) A specific function of light in the process of photosynthesis is

(a) Reduction of CO_2 ○ (b) To oxidise other molecules ○

(b) Split water molecules ○ (d) None of these ○

(6) Organelle associated with photorespiration is

(a) Ribosome ○ (b) Peroxisome ○

(c) Nucleosome ○ (d) Mesosome ○

(7) The wavelength of light most absorbed during photosynthesis is

(a) 700 nm ○ (b) 660 nm ○

(c) 550 nm ○ (d) 400 nm ○

(8) In photosynthesis, photolysis of water is used in

(a) Reduction of NADP ○ (b) Oxidation of NADP ○

(e) Oxidation of FAD ○ (d) None of the above ○

(9) Number of cell organelles involved in photorespiration is

(a) One ○ (b) Two ○ (c) Three ○ (d) Four ○

(10) Maximum photosynthesis occurs in

(a) Red light ○ (b) Green light ○

(b) Blue light ○ (d) Yellow light ○

(11) Special feature of C_4 plant is

(a) Thin cuticle ○ (b) Multiple epidermis ○

(b) Kranz anatomy ○ (d) Both a) and b) ○

(12) Carbon dioxide is fixed in

(a) Light reaction ○ (b) Dark reaction ○

(b) Photorespiration ○ (d) Spliting of water ○

(13) Which photosynthetic cycle is performed in mesophyll cells of sugar cane ?

(a) C_4 ○ (b) C_3 ○ (c) C_2 ○ (d) C_1 ○

(14) Which one of the following is a C_4 plant

(a) Tomato ○ (b) Sugarcane ○

(c) Apple ○ (d) Mango ○

2. Answer the following questions in short :

(1) Define photosynthesis.

(2) Which equation was given by Scientist Niel for photosynthesis ?

(3) What is photolysis ?

(4) Give full forms of PGA, OAA, RuBP

(5) What is RuBisCO ? What is its full form ?

(6) What are the end products of photosynthesis ?

(7) In C_3 pathway, how many ATP molecules are required for the synthesis of one molecule of glucose ?

(8) What is cyclic electron transport ?

(9) Define Non-cyclic photophosphorylation.

3. Do as directed :

(1) Write short note on Kranz anatomy.

(2) Differentiate between C_3 and C_4 plants

(3) What is RuBisCO ? Explain its role in C_3 and C_4 photosynthesis

(4) Describe cyclic photophosphorylation.

(5) Write a note on non-cyclic photophosphorylation.

(6) Explain carboxylation step of Calvin cycle.

(7) Explain why light reaction is prerequisite for biosynthetic phase.

(8) Describe the structure of chloroplast.

(9) Explain splitting of water.

(10) Describe the Kranz anatomy.

(11) Explain why the productivity is more in C_4 plants as compared to C_3.

4. Answer the following questions in detail :

(1) What is Calvin cycle ? Describe in detail.

(2) Describe various factors which affect the rate of photosynthesis.

(3) Describe photorespiration.

(4) Explain the photophosphorylation.

(5) Explain light phase of photosynthesis.

(6) Describe the biosynthetic phase of photosynthesis

(7) Explain chemiosmotic hypothesis.

(8) Describe C_4 pathway.