12. Photosynthesis

Can you recall?

1. Why energy is essential in different life processes?
2. How do we get energy?

Use your brain power

Justify: All life on earth is 'bottled solar energy'.

Photosynthesis is the only process on earth by which solar energy is trapped by green plants and converted into food. Photosynthesis may be defined as *synthesis of carbohydrates (glucose) from inorganic materials like* CO_2 *and* H_2O *with the help of solar energy trapped by pigments like chlorophyll*.

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

This process is unique to green plants and is the final light energy trapping process on which all life ultimately depends. It is one of the most massive chemical processes going on earth.

Atmosphere contains only about 0.03 percent carbon dioxide by volume. This small percentage represents 2200 billion tons of CO_2 in the atmosphere. The oceans contain over 50 times by amount of atmospheric CO_2 in the form of dissolved gas or carbonates. From these two sources, about 70 billion tons of carbon is fixed by the green plants annually.

12.1 Chloroplasts :

These are mainly located in the mesophyll cells of leaves. The CO_2 reaches them through the stomata and water reaches them through veins. In higher plants, the chloroplasts are discoid or lens-shaped. Each chloroplast is bounded by double membrane. Inside the membranes is found a ground substance, the *stroma*. Inside the stroma is found a system of chlorophyll bearing double-membrane sacs or lamellae. These are stacked one above the other to form *grana* (singular, granum). Individual sacs in each *granum* are known as *thylakoids*.

All the pigments chlorophylls, carotenes and xanthophylls are located in the thylakoid membranes. These pigments absorb light of a specific spectrum in the visible region. The pigments are fat soluble and located in the lipid part of the membrane. With the help of certain enzymes, they participate in the conversion of solar energy into ATP and NADPH. The enzymes of stroma utilize ATP and NADPH to produce carbohydrates.

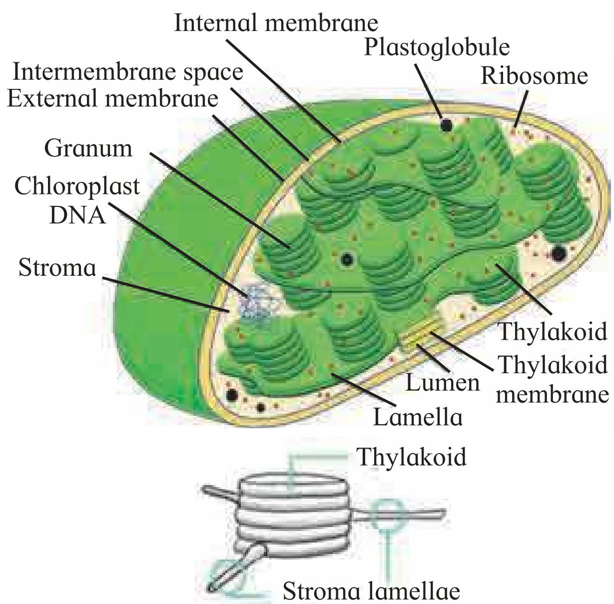


Fig. 12.1 Chloroplasts

Two predominant types of chlorophylls :

Chlorophyll *a* and *b* differ in the nature of groups. Chlorophyll *a* has a methyl group ($-CH_3$) while chlorophyll *b* has an aldehyde group (-CHO). Chemically chlorophyll molecule consists of two parts head of tetrapyrrol the *Porphyrin ring* and a long hydrocarbon tail called phytol attached to the porphyrin group. Carotenoids are lipid compound present universally in almost all the higher plants and several micro-organisms. They are usually red, orange, yellow, brown, and are associated with chlorophyll. They are of two types - the *carotenes* and *xanthophylls*. The carotenes ($C_{40}H_{56}$) are orange red and xanthophylls contain oxygen. The light energy absorbed by the carotenoids is transferred to chlorophyll *a* to be utilized in photosynthesis.

Internet my friend

Collect information : Why does chlorophyll appear red in reflected light and green in transmitted light?

Activity 1

Grind the spinach leaves in small quantity of acetone / nail paint remover. Mix the contents properly and filter with filter paper in test-tube. Test-tube contains green filtrate. Take the test-tube in dark-room and put a flash of torch on it. Now, solution appears red. Why does this occur? Which phenomenon is this? Discuss this with your physics, chemistry and biology teachers.

Activity 2

To separate the chloroplast pigments by paper chromatography. Concentrate the extracted chlorophyll solution by evaporation. Apply a drop of it at one end, 2cm away from edge of a strip of chromatography paper and allow it to dry thoroughly. Take a mixture of petroleum ether and acetone in the ratio of 9 : 1 at temperature of 40 to 60^{0}C. Hang the strip in the jar with its loaded end dipping in the solvent. Close the jar tightly and keep it for an hour. The pigments separate into distinct green and yellow bands of chlorophyll and carotenoid respectively.

Can you tell?

Tomatoes, carrots and chillies are red in colour due to presence of pigments. Name the pigment.

All photosynthetic plants have these pigments that absorb light between the red and blue region of the spectrum. Carotenoids found mainly in higher plants absorb primarily in the violet to blue regions of the spectrum. They not only absorb light energy and transfer it to chlorophyll but also protect the chlorophyll molecule from photo-oxidation.

12.2 Nature of Light :

Light is a form of energy. It travels as stream of tiny particles called photons. A photon contains a quantum of light. Light has different wavelengths having different colors. One can see electromagnetic radiation with wavelengths ranging from 390nm to 730nm. This part of the spectrum is called the Visible light. It lies between wavelengths of ultraviolet and infra-red.

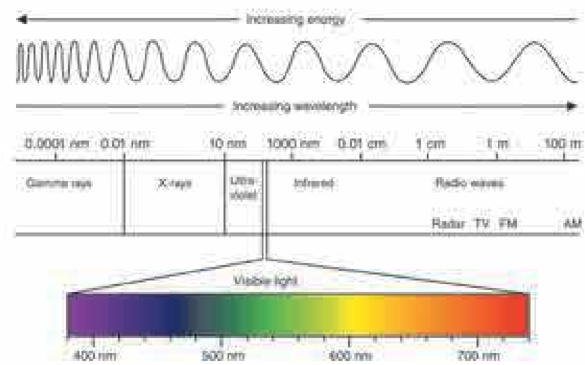
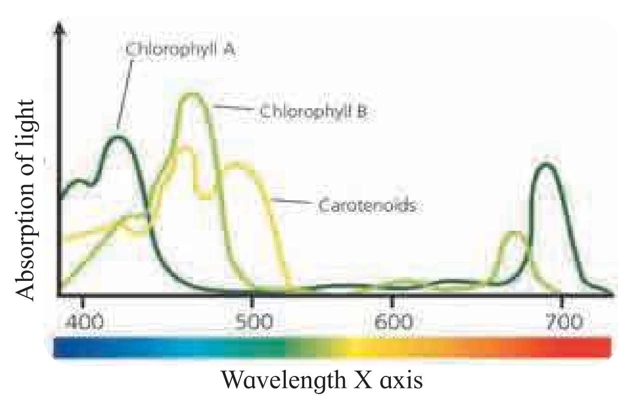


Fig. 12.2 Electromagentic spectrum of light

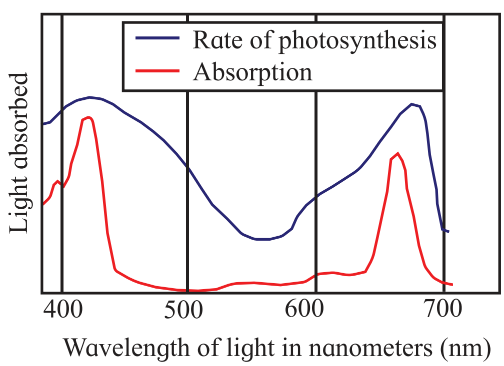
Absorption and Action spectrum : All the pigments of the chloroplast absorb light quanta or photons and transfer the absorbed energy to chlorophyll *a*. The amount of light absorbed at each wavelength can be shown in the form of a graph. It shows different curves at different wavelengths. Such a curve which shows the amount of light absorbed at each wavelength is termed as *Absorption spectrum*.



Graph 12.3 Absorption spectrum

The absorption spectrum of chlorophyll *a* and *b* clearly shows that more light energy is absorbed at blue, violet and red wavelengths of the visible spectrum. The relative rate of photosynthesis at different wavelengths indicates close relationship with absorption spectrum of chlorophyll *a* and *b*. This curve that shows the rate of photosynthesis at different wavelengths is called *Action Spectrum*.

Action spectrum of photosynthesis differs from the absorption spectrum. There is quite a lot of photosynthetic activity even in parts of the spectrum where chlorophyll *a* absorb little light. This infers that the light energy absorbed by other pigments (yellow and orange carotenoids and also other forms of chlorophyll) is transferred to chlorophyll *a*.



Graph 12.4 Action spectrum of photosysnthesis

Can you tell?

1. What made Hill to perform his experiment?
2. Distinguish between action spectrum and absorption spectrum.
3. Draw well labeled diagram of chloroplast.

Use your brain power

The photosysthetic lamellae taken out from a chloroplast and suspended in a *nutrient medium* in the presence of CO_2 and light. Will they synthesize sugar or not?

12.3 Mechanism of Photosynthesis :

In 1931, Van Neil proved that bacteria used H_2S and CO_2 to synthesize carbohydrates as follows :

$$6CO_2 + 12H_2S \longrightarrow C_6H_{12}O_6 + 6H_2O + 12S \downarrow$$

This led Van Neil to postulate that in green plants, water is utilized in place of H_2S and O_2 is evolved in place of sulphur. Ruben (in 1941) confirmed it in *Chlorella*. He used water labeled with heavy oxygen ($^{18}O_2$) i.e. $H_2{}^{18}O$.

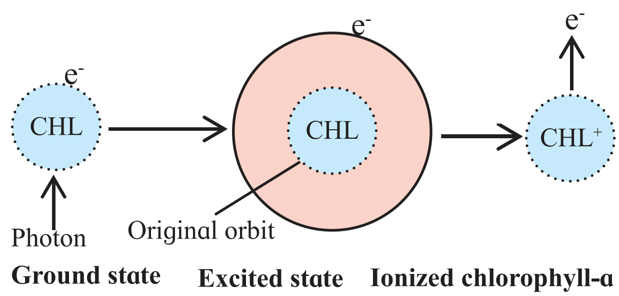


Fig. 12.5 Photoexitation of chlorophyll-a

The oxygen evolved contain $^{18}O_2$ thereby proving Van Neil's hypothesis that oxygen evolved in photosynthesis comes from water. This leads to the currently accepted general equation of photosynthesis -

$$6CO_2 + 12H_2{}^{18}O \xrightarrow{\text{Light}} C_6H_{12}O_6 + 6H_2O + 6\,{}^{18}O_2$$

In 1937, R. Hill demonstrated that isolated chloroplasts evolved oxygen when they were illuminated in the presence of a suitable electron acceptor such as *ferricyanide*. Ferricyanide is reduced to ferrocyanide by photolysis of water. This is called Hill reaction.

Think about it

Large number of gas bubbles are evolved during day time in a pond of water.

Thus Hill reaction proves that :

i. In photosynthesis, oxygen is released from water.

ii. Electrons for the reduction of CO_2 are obtained from water.

According to Arnon, in this process light energy is converted to chemical energy. This energy is stored in ATP and NADPH is formed as hydrogen donor. This ATP formation is known as photophosphorylation.

In modern concept, the process of photosynthesis is an oxidation and reduction process in which water is oxidized (to release O_2) and CO_2 is reduced to form sugar. It consists of two successive series of reactions. The first reaction requires light and is called *Light or Hill reaction*. Second reaction does not require light and is called *Dark or Blackman reaction*. Of the two reactions, the former is a photochemical reaction, while the latter is a biochemical reaction.

Think about it

Does moon light support photosynthesis?

12.4 Light reaction :

In light reaction, solar energy is trapped by chlorophyll and stored in the form of chemical energy as ATP and in the form of reducing power as $NADPH_2$. Oxygen is evolved in the light reaction by splitting of water.

When a photon is absorbed by chlorophyll molecule, an electron is boosted to higher energy level. To boost an electron, a photon must have a certain minimum quantity of energy called *quantum energy*. A molecule that has absorbed a photon is in energy rich *excited state*. When the light source is turned off, the high energy electrons return rapidly to their normal low energy orbitals as the excited molecule reverts to its original stable condition, called the *ground state*.

Reaction centre : The light absorbing pigments are located in the thylakoid membranes. They are arranged in clusters of chlorophyll and accessory pigments along with special types of chlorophyll molecules P_{680} and P_{700} (the letter P stands for Pigment and 680 and 700 for the wavelengths of light at which these molecules show maximum absorbance). P_{680} and P_{700} molecules form the *Reaction centers or Photocenters*.

The accessory pigments and other chlorophyll molecule harvest solar energy and pass it on the reaction centers. These are called *Light harvesting or Antenna molecule*. They function to absorb light energy, which they transmit at a very high rate to the reaction center where the photochemical act occurs.

Photosystems I and II : The thylakoid membranes of chloroplasts have two kinds of photosystems, each with its own set of light harvesting chlorophyll and carotenoid molecules. Chlorophyll and accessory pigments help to capture light over larger area and pass it on to the photocenters. Thus, a photon absorbed anywhere in the harvesting zone of a P_{680} center can pass it energy to the P_{680} molecule. The cluster of pigment molecules which transfer their energy to P_{680} absorb at or below the wavelength 680nm. Together with P_{680} they form *Photosystem-II* or *PS-II*. Likewise, P_{700} forms *Photosystem-I* or *PS-I* along with pigment molecule which absorbs light at or below 700nm.

Photosystem II : This system brings about photolysis of water and release of oxygen. In this act, when PS-II absorbs light, electrons are released and chlorophyll molecule is oxidized. The electrons emitted by P_{680} (PS-II) are ultimately trapped by P_{700} (PS-I).

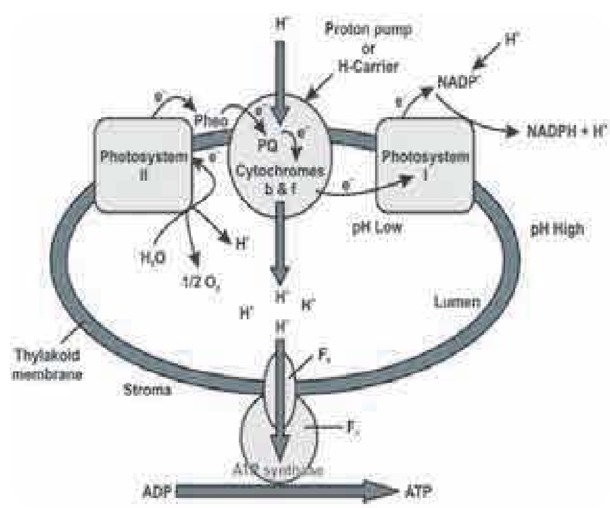


Fig. 12.6 ATP synthesis through chemiosmosis

The oxidized P_{680} regains its electrons by the photolysis of water as follows:

$$4H_2O \longrightarrow 4H^+ + 4OH^-$$
$$4OH^- \longrightarrow 4(OH) + 4e^-$$
$$4OH \longrightarrow 2H_2O + O_2$$
$$4H_2O \longrightarrow 2H_2O + O_2\uparrow + 4H^+ + 4e^-$$

Oxygen is given out as byproduct by the photosynthesizing plants. Protons (H^+) accumulate inside the thylakoid resulting in a *Proton gradient*.

The energy released by the protons when they defuse across the thylakoid membrane into the stroma against the H^+ concentration gradient is used to produce ATP.

Photosystem I : When light quanta are absorbed by photosystem I (P_{700}), energy rich electrons are emitted from the reaction center. These flow down a chain of electron carriers to NADP along with the proton generated by splitting of water. This result in the formation of NADPH.

Hydrogen attached to NADPH is used for reduction of CO_2 in dark reaction. This is also called *Reducing power of the cell*.

12.5 Photophosphorylation :

Formation of ATP in the chloroplasts in presence of light is called photophosphorylation. It takes place in the two forms.

i. Cyclic photophosphorylation :

Illumination of photosystem-I causes electrons to move continuously out of the reaction center of photosystem-I and back to it.

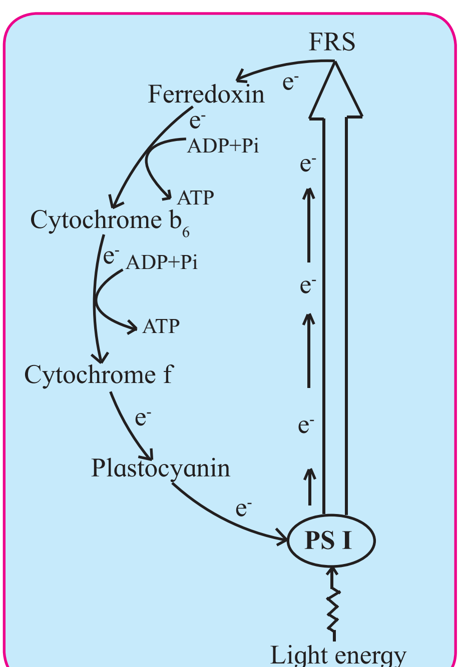


Fig. 12.7 Cyclic photophosphorylation

The cyclic electron-flow is accompanied by the photophosphorylation of ADP to yield ATP. This is termed as *Cyclic photophosphorylation*. Since this process involves only pigment system I, photolysis of water and consequent evolution of oxygen does not takes place.

ii. Non-cyclic photophosphorylation :

It involves both PS-I and PS-II photosystems. In this case, electron transport chain starts with the release of electrons from PS-II. In this chain high energy electrons released from PS-II do not return to PS-II but, after passing through an electron transport chain, reach PS-I, which in turn donates it to reduce $NADP^+$ to NADPH. The reduced $NADP^+$ (NADPH) is utilized for the reduction of CO_2 in the dark reaction.

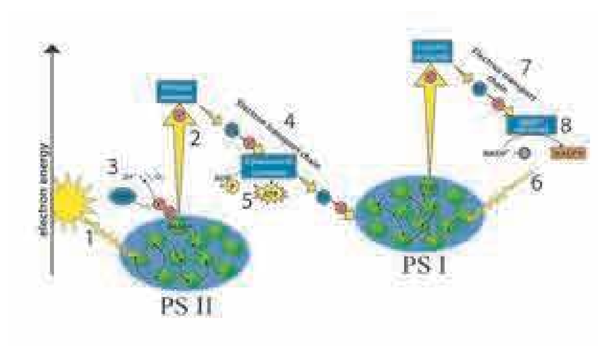


Fig. 12.8 Non-cyclic photophosphorylation

Electron-deficient PS-II brings about oxidation of water-molecule. Due to this, protons, electrons and oxygen atom are released. Electrons are taken up by PS-II itself to return to reduced state, protons are accepted by $NADP^+$ where as oxygen is released.

As in this process, high energy electrons released from PS-II do not return to PS-II and it is accompanied with ATP formation, this is called *Non-cyclic photophosphorylation*.

Thus, during the photochemical reactions, photolysis of water takes place, O_2 is released and ATP and NADPH are synthesized. ATP and NADPH molecules function as vehicles for transfer of energy of sunlight into dark reaction leaving to carbon fixation. In this reaction CO_2 is reduced to carbohydrate.

The light reaction gives rise to two important products : i. A reducing agent NADPH and ii. An energy rich compound ATP. Both these are utilized in the dark phase of photosynthesis.

12.6 Dark reaction :

Carbon fixation occurs in the stroma by a series of enzyme catalyzed steps. Molecules of ATP and NADPH produced in the thylakoids (light reaction) come in the stroma where carbohydrates are synthesized.

The path of carbon fixation in dark reaction through intermediate compounds leading to the formation of sugar and starch was worked out by **Calvin, Benson** and their co -workers. For this, *Calvin* was awarded *Nobel Prize* in 1961.

Path of carbon was studied with the help of radioactive tracer technique using *Chlorella*, a unicellular green alga and radioactive $^{14}CO_2$. With the help of radioactive carbon, it becomes possible to trace the intermediate steps of fixation of $^{14}CO_2$. The various steps in the dark reactions (Calvin cycle / C-3 pathway, fig. 12.10) are as follows:

1. Carboxylation : CO_2 reduction starts with a 5-carbon sugar, ribulose-1,5-bisphosphate (RuBP). It is a 5-carbon sugar (pentose) with two phosphate groups attached to it.

RuBP reacts with CO_2 to produce a short - lived 6-carbon intermediate in the presence of an enzyme *RuBP carboxylase* or *Rubisco* and immidiately splits into 3-carbon compound, 3-phosphoglyceric acid (3-PGA). Rubisco is a large protein molecule and comprises 16% of the chloroplast proteins.

2. Glycolytic Reversal : Molecules of 3-PGA form 1,3-diphosphoglyceric acid utilizing ATP molecules. These are reduced to glyceraldehyde-3-phosphate (3-PGAL) by NADPH supplied by the light reactions of photosynthesis.

For the Calvin cycle to run continuously,

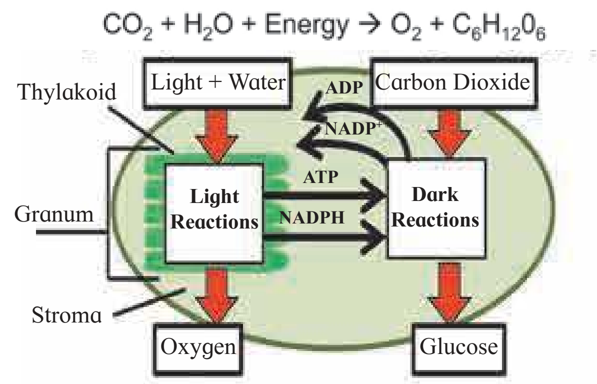


Fig. 12.9 Relation between light and dark reaction

there must be sufficient amount of RuBP which accepts CO_2 and a regular supply of ATP and NADPH. Out of each of 12 molecules of 3-phosphoglyceraldehyde (3-PGAL), 2 molecules are used for synthesis of one glucose molecule and remaining 10 molecules are used for regeneration of 6 molecules of RuBP.

3. Regeneration of RuBP : Through a series of complex reactions, 10 molecules of 3-PGAL are used for regenration of six molecules of RuBP at the cost of 6 ATP. For this purpose, six turns of Calvin cycle are needed to be operated so that a molecule of glucose can be synthesized.

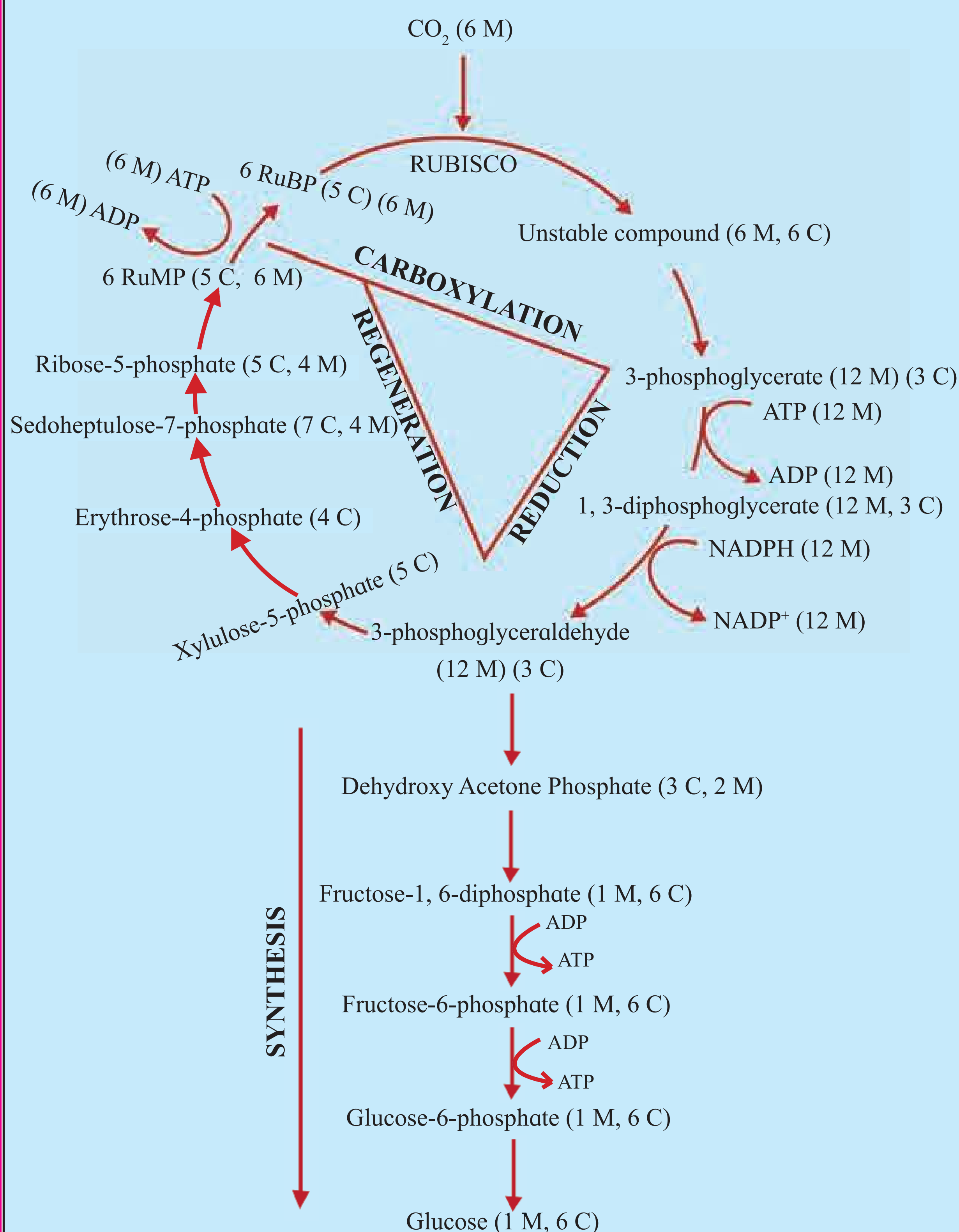
Plants form a variety of organic compounds required for its structure and function through these complex reactions.

Thus, for every 6 molecules of CO_2 and Ribulose-1, 5-biphosphate used, 12 molecules of 3-phosphoglyceraldehyde are produced. Out of these 12 molecules, only two are utilized for the formation of a molecule of glucose; the other 10 molecules are converted into ribulose-1, 5-biphosphate which combines with fresh CO_2.

Thus, the Calvin cycle regenerates ADP and NADP required for the light reaction.

i. Light Reaction (in granum) :

1. $24H_2O \longrightarrow 24OH^- + 24H^+$
2. $24OH^- \longrightarrow 24OH + 24e^-$
3. $24e^- + 24H^+ + 12NADP^+ \longrightarrow 12NADPH$
4. $18ADP + 18Pi \longrightarrow 18ATP$
5. $24OH \longrightarrow 12H_2O + 6O_2\uparrow$



CO_2 (6 M)
RUBISCO
6 RuBP (5 C) (6 M)
Unstable compound (6 M, 6 C)
(6 M) ATP
(6 M) ADP
6 RuMP (5 C, 6 M)
CARBOXYLATION
REGENERATION
REDUCTION
3-phosphoglycerate (12 M) (3 C)
ATP (12 M)
ADP (12 M)
1, 3-diphosphoglycerate (12 M, 3 C)
NADPH (12 M)
$NADP^+$ (12 M)
3-phosphoglyceraldehyde
(12 M) (3 C)
Ribose-5-phosphate (5 C, 4 M)
Sedoheptulose-7-phosphate (7 C, 4 M)
Erythrose-4-phosphate (4 C)
Xylulose-5-phosphate (5 C)
SYNTHESIS
Dehydroxy Acetone Phosphate (3 C, 2 M)
Fructose-1, 6-diphosphate (1 M, 6 C)
ADP
ATP
Fructose-6-phosphate (1 M, 6 C)
ADP
ATP
Glucose-6-phosphate (1 M, 6 C)
Glucose (1 M, 6 C)

ii. Dark reaction (in stroma) :

$$6CO_2 + 18ATP + 12NADPH \longrightarrow C_6H_{12}O_6 + 6H_2O + 18ADP + 18Pi + 12NADP^+$$

$$(i + ii)\ 6CO_2 + 24H_2O \xrightarrow[\text{Chloroplast}]{\text{Light}} C_6H_{12}O_6 + 18H_2O + 6O_2 \uparrow$$

Can you tell?

1. How chlorophyll - a is excited? Show it with a diagram.
2. Describe Calvin's cycle.
3. Draw a flowchart of non-cyclic photophosphorylation.

12.7 Photorespiration :

Photorespiration occurs under the conditions like high temperature, bright light, high oxygen and low CO_2 concentration. It is a wasteful process linked with C_3-Cycle, where instead of fixation of CO_2 it is given out.

It involves three organelles chloroplast peroxisomes and mitochondria and occurs in a series of cyclic reactions which is also called PCO cycle. Enzyme Rubisco acts as oxygenase at higher concentration of O_2 and photorespiration begins. When RuBP reacts with O_2 rather than CO_2 to form a 3-carbon compound (PGA) and 2-carbon compound phosphologycolate. Later is converted to glycolate which is shuttled out of the chloroplast into the peroxisomes.

In peroxisomes, enzyme glycolate oxidase converts glycolate into glyoxylate, which is converted into amino acid glycine by transamination. In mitochondria, two molecules of glycine are converted into serine (amino acid) and CO_2 is given out. Thus, it looses 25% of photosynthetically fixed carbon. Serine is transported back to peroxisomes and converted into glycerate. It is shuttled back to chloroplast to undergo phosphorylation and utilized in formation of 3-PGA, which get utilized in C_3 pathway.

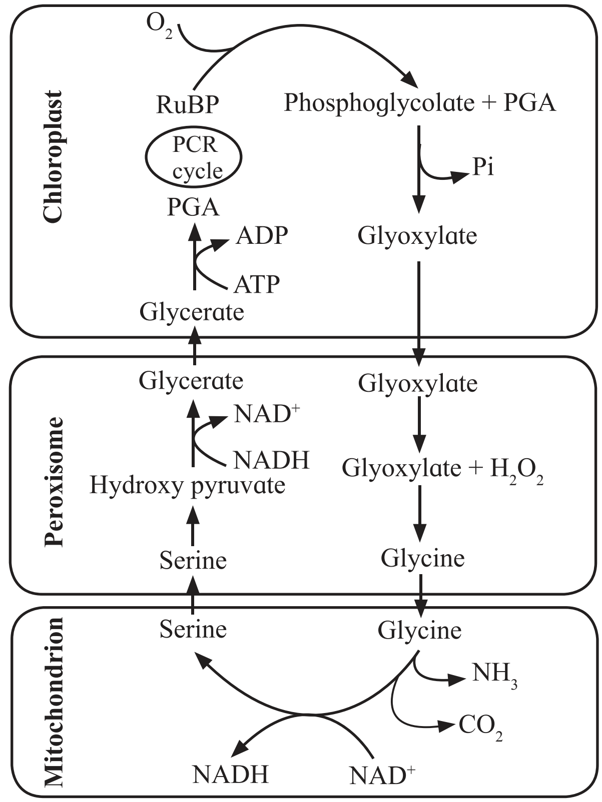


Fig. 12.11 Photorespiration

12.8 C_4 pathway or Hatch-Slack pathway :

M. D. Hatch and C. R. Slack while working on sugarcane found four carbon compound (dicarboxylic acid) as the first stable product of photosynthesis. It has been found to occur in tropical and sub-tropical grasses and some dicotyledons. Some of the important plants are sugarcane, maize, *Sorghum* etc.

The plants in which CO_2 fixation takes place by Calvin cycle are called C_3 plants, because first product of CO_2 fixation is a 3-carbon phosphoglyceric acid. But in Hatch-Slack pathway, first product of CO_2 fixation is a 4-carbon compound, oxaloacetic acid. Hence such plants are called C_4 plants.

Anatomy of leaves of C_4 plants is different from leaves of C_3 plants. C_4 plants show *Kranz anatomy*. In the leaves of such plants, palisade tissue is absent. There is a bundle sheath around the vascular bundles. The chloroplasts in the bundle - sheath cells are large and without or less developed grana, where as in the mesophyll cells the chloroplasts are small but with well-developed grana.

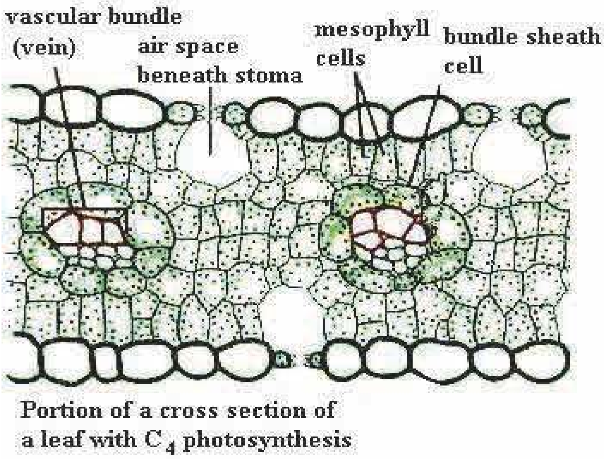


Fig. 12.12 Kranz anatomy of C_4 plant

CO_2 taken from atmosphere is accepted by a 3-carbon compound, phosphoenolpyruvic acid in the chloroplasts of mesophyll cells, leading to the formation of 4-C compound, oxaloacetic acid with the help of enzyme pepco. It is converted to another 4-C compound, the malic acid. It is transported to the chloroplasts of bundle sheath cells. Here, malic acid (4-C) is converted to pyruvic acid (3-C) with the release of CO_2 in the cytoplasm. Thus concentration of CO_2 increases in the bundle sheath cells.

Chloroplasts of these cells contain enzymes of Calvin cycle. Because of high concentration of CO_2, RuBP carboxylase participates in Calvin cycle and not photorespiration. Sugar formed in Calvin cycle is transported into the phloem.

Pyruvic acid generated in the bundle sheath cells re-enters mesophyll cells and regenerates phosphoenolpyruvic acid by consuming one ATP.

Since this conversion results in the formation of AMP (not ADP), two ATP are required to regenerate ATP from AMP. Thus C_4 pathway needs 12 additional ATP. The C_3 pathway requires 18 ATP for the synthesis of one glucose molecule, whereas C_4 pathway requires 30 ATP.

Thus C_4 plants are better photosynthesizers and there is no photorespiration in these plants.

12.9 CAM-Crassulacean Acid Metabolism:

It is one more alternative pathway of carbon fixation found in desert plants. It was first reported in the family Crassulaceae, so called as CAM (Crassulacean Acid Metabolism).

In CAM plants, stomata are scotoactive i.e. active during night, so initial CO_2 fixation occurs in night.

Thus C4 pathway fix CO_2 at night and reduce CO_2 in day time via the C_3 pathway by using NADPH formed during the day. PEP caboxylase and Rubisco are present in the mesophyll cell (no *Kranz* anatomy).

Formation of malic acid during dark is called acidification (phase I).

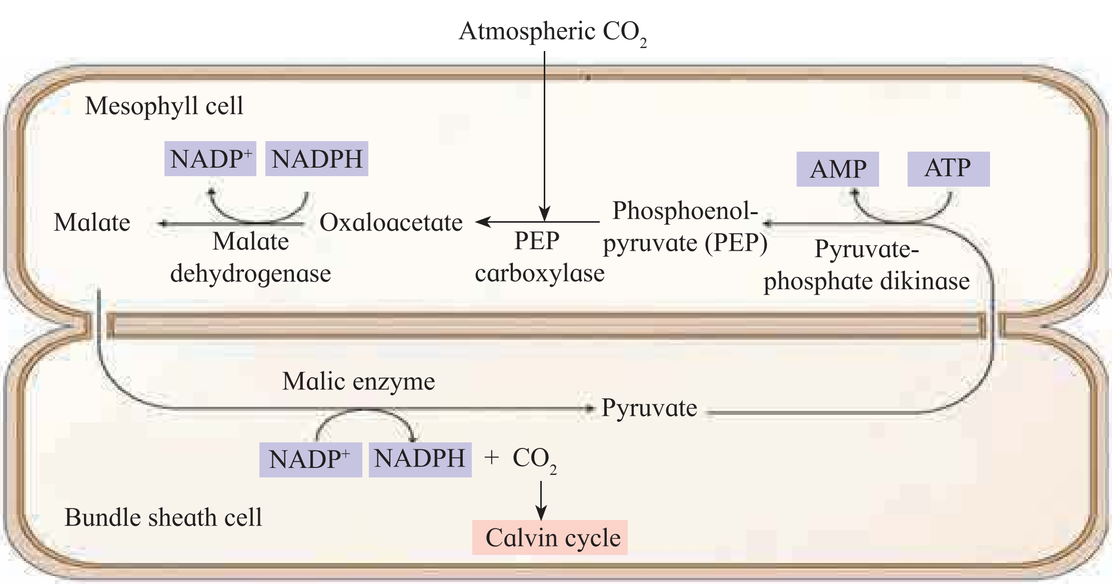


Fig. 12.13 C_4 Pathway

Malate is stored in vacuoles during the night. Malate releases CO_2 during the day for C_3 pathway within the same cell is called deacidification (phase II).

Examples of CAM plants : *Kalanchoe*, *Opuntia*, *Aloe* etc.

The Chemical reactions of the carbon di-oxide fixation and its assimilation are similar to that of C4 plants.

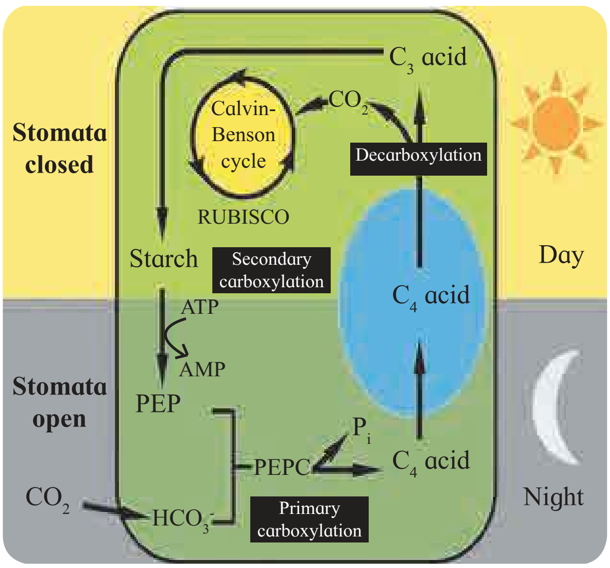


Fig. 12.14 Crassulacean acid metabolism

Can you tell?

1. C_4 plants are more productive. Why?
2. Xerophytic plants survive in high temperature. How?
3. Summarise the photosynthetic reaction.
4. Compare C_4 plants and CAM plants.

12.10 Factors affecting Photosynthesis :

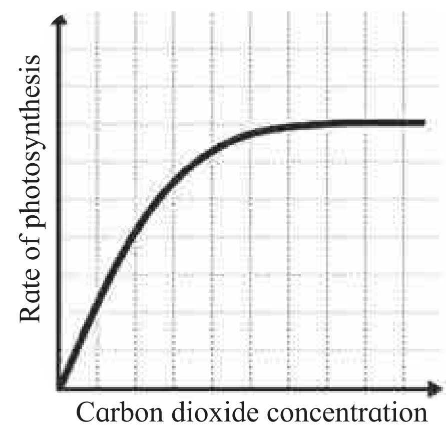
Like all other physiological processes, photosynthesis is also influenced by a number of factors.

A. External Factors :

Light : It is an essential factor as it supplies the energy necessary for photosynthesis. Both quality and intensity of light affect photosynthesis. Highest rate of photosynthesis takes place in the red rays and then come the blue rays. In a forest canopy the rate of photosynthesis decreases considerably in plants growing under the it.

In most of the plants, photosynthesis is maximum in bright diffused sunlight. It decreases in strong light and again slows down in the light of very low intensity. It has also been found that uninterrupted and continuous photosynthesis for relatively long periods of time may be sustained without any visible damage to the plant.

Carbon dioxide : The main source of CO_2 in land plants is the atmosphere, which contains only 0.3% of the gas. Under normal conditions of temperature and light, carbon dioxide acts as a limiting factor in photosynthesis. An increase in concentration of CO_2 increases the photosynthesis. The increase in CO_2 to about 1% is generally advantageous to most of the plants. Higher concentration of the gas has an inhibitory effect on photosynthesis.



Graph. 12.15 Effect of CO_2 concentration

Temperature : Like all other physiological processes, photosynthesis also needs a suitable temperature. In the presence of plenty of light and carbon dioxide, photosynthesis increases with the rise of temperature till it becomes maximum. After that there is a decrease or fall in the rate of the process.

The optimum temperature at which the photosynthesis is maximum is 25 – 30^{0}C, though in certain plants like *Opuntia*, photosynthesis takes place at as high as 55^{0}C. This is known as the maximum temperature. The temperature at which the process just starts is the minimum temperature.

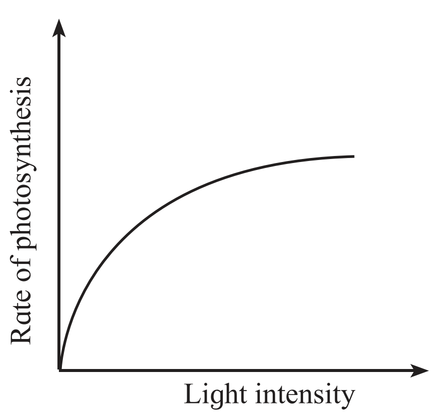
Water : Being one of the raw material, water is also necessary for the photosynthetic process. An increase in water content of the leaf results in the corresponding increase in the rate of photosynthesis. Thus the limiting effect of water is not direct but indirect. It is mainly due to the fact that it helps in maintaining the turgidity of the assimilatory cells and the proper hydration of their protoplasm.

B. Internal Factors : Though the presence of chlorophyll is essential for photosynthesis but the rate of photosynthesis is proportional to the quantity of chlorophyll present. It is because of the fact that chlorophyll merely acts as a biocatalyst and hence a small quantity is quite enough to maintain the large bulk of the reacting substances.

The final product in the photosynthesis reaction is sugar and its accumulation in the cells slow down the process of photosynthesis. The thickness of cuticle and epidermis of the leaf, the size and distribution of intercellular spaces and the distribution of the stomata and the development of chlorenchyma and other tissues also affects the rate of photosynthesis.

Blackman's law of limiting factors :

The Blackman's law of limiting factors states that when a process is conditioned as to its rapidity by a number of separate factors, the rate of the process is controlld by the pace of the "slowest factor".



Graph. 12.16 Light intensity and Photosynthesis

The slowest factor is that factor which is present in the lowest or minimum concentration in relation to others. The law of limiting factor can be explained by taking two external factors such as carbon dioxide and light. Suppose a plant photosynthesizing at a fixed light intensity sufficient to utilize 10mg of CO_2 per hour only.

On increasing the CO_2 concentration, the photosynthetic rate also goes on increasing. Now, if the CO_2 concentration is further increased, no increase in the rate of photosynthesis will be noted. Thus in this case light becomes the limiting factor. Under such circumstances, the rate of photosynthesis can be increased only by increasing the light intensity.

This evidently shows that the photosynthetic rate responds to one factor alone at a time and there would be a sharp break in the curve and a plateau formed exactly at the point where another factor becomes limiting. If any one of the other factors which is kept constant (say, light) is increased, the photosynthetic rate increases again reaching and optimum where again another factor become limiting.

Significance : This anabolic process uses inoganic substances and produces food for all life directly or indirectly. This process transforms solar energy into chemical energy. The released by product O_2 is necessary not only for aerobic respiration in living organisms but also used in forming protective ozone layer around earth. This process is also helping us in providing fossil fuels, coals, petroleum and natural gas.

Exercise

1. Choose correct option

A. A cell that lacks chloroplast does not
a. evolve carbon dioxide
b. liberate oxygen
c. require water
d. utilize carbohydrates.

B. Energy is transferred from the light reaction step to the dark reaction step by
a. chlorophyll b. ADP
c. ATP d. RuBP

C. Which one is wrong in photorespiration
a. It occurs in chloroplasts
b. It occurs in day time only
c. It is characteristic of C_4-plants
c. It is characteristic of C_3-plants

D. Non-cyclic photophorylation differs from cyclic photophosphorylation in that former
a. involves only PS I
b. Include evolution of O_2
c. involves formation of assimilatory power
d. both 'b' and 'c'

E. For fixation of 6 molecules of CO_2 and formation of one molecule of glucose in Calvin cycle, requires
a. 3 ATP and 2 $NADPH_2$
b. 18 ATP and 12 $NADPH_2$
c. 30 ATP and 18 $NADPH_2$
d. 6 ATP and 6 $NADPH_2$

F. In maize and wheat the first stable products formed in bundle sheath cells respectively are
a. OAA and PEPA
b. OAA and OAA
c. OAA and 3PGA
d. 3PGA and OAA

G. C_4 pathway is also called as dicarboxylation pathway because
a. RuBP + CO_2 in bundle sheath cells
b. PEPA + CO_2 in mesophyll cells
c. both 'a' and 'b'
d. It occurs in presence of intensive light

H. The head and tail of chlorophyll are made up of
a. porphyrin and phytin respectively
b. pyrrole and tetrapyrrole respectively
c. prophyrin and phyrol respictively
d. tetrapyrole and pyrrole respectively

I. The net result of photo-oxidation of water is release of
a. electron and proton
b. proton and oxygen
c. proton, electron and oxygen
d. electron and oxygen

J. For fixing one molecule of CO_2 in Calvin cycle, are required
a. 3ATP + $1NADPH_2$
b. 3ATP + $2NADPH_2$
c. 2ATP + $3NADPH_2$
d. 3ATP + $3NADPH_2$

K. In presence of high concentration of oxygen, RuBP carboxylase converts RuBP carboxylase converts RuBP to
a. Malic acid and PEP
b. PGA and PEP
c. PGA and malic acid
d. PGA and phosphoglycolate

L. The sequential order in electron transport from PSII to PSI of photosynthesis is
a. FeS, PQ, PC and Cytochrome
b. FeS, PQ, Cytochrome and PC
c. PQ, Cytochrome, PC and FeS
d. PC, Cytochrome, FeS, PQ

2. Answer the following questions

A. Describe the light-dependent steps of photosynthesis. How are they linked to the dark reactions?

B. Distinguish between: a. respiration and photorespiration b. absorption spectrum and action spectrum c. cyclic photophosphorylation and non-cyclic photophosphorylation

C. What are the steps that are common to C_3 and C_4 photosynthesis?

D. Are the enzymes that catalyse the dark reactions of carbon fixation located inside the thylakoids or outside the thylakoids?

E. Calvin cycle consists of three phases, what are they? Explain the significance of each of them.

F. Why are the plants that consume more than the usual 18 ATP to produce 1 molecule of glucose favoured in tropical regions?

G. What is the advantage of having more than one pigment molecule in a photocentre?

H. Why does chlorophyll appear green in reflected light and red transmitted light? Explain the significance of these phenomena in terms of photosynthesis.

I. Explain why photosynthesis is considered the most important process in the biosphere.

J. Why is photolysis of water accompained with non-cyclic photophosphorylation?

K. In C-4 plants, why is C-3 pathway operated in bundle sheath cells only?

L. What would have happed if C-4 plants did not have Kranz anatomy?

M. Why does RnBisCo carry out preferentially carboxylation than oxygenation in C_4 plants?

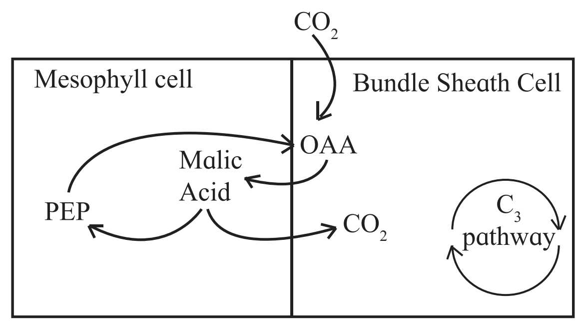
N. What would have happened if plants did not have accessoy pigments?

O. How can you identify whether the plant is C_3 or C_4? Explain / Justify.

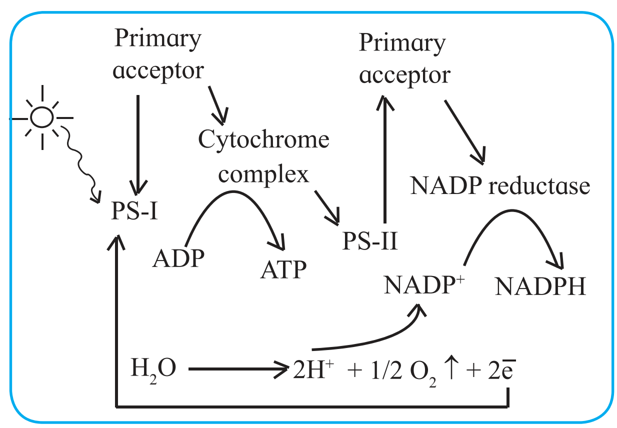
P. In C_4 plants, bundle sheath cells carrying out Calvin cycle are very few in number. Through also, C_4 plants are highly productive. Explain.

Q. What is functional significance of Kranz anatomy?

3. Correct the pathway and name it



4. Is there something wrong in following schematic presentation? If yes, correct it so that photosynthesis will be operated



Practical / Project :

1. Draw schematic presentation of different processes / cycles / reactions related to photosynthesis.
2. Check the effects of different factors on photosynthesis under the guidance of teacher.