Photosynthesis

Photosynthesis: The literary meaning of photosynthesis is 'synthesis with the help of light'. This term is usually applied in plant physiology which means the plant synthesize organic matter in presence of light. Photosynthesis is also called as carbon assimilation and is represented by the equation-

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

Photosynthesis occurs in two stages. In the first stage, *light-dependent reactions* or *light reactions* capture the energy of light and use it to make the energy-storage molecules ATP and NADPH. During the second stage, the *light-independent reactions* known as dark reaction, use these products to capture and reduce carbon dioxide.

Photolysis of water:

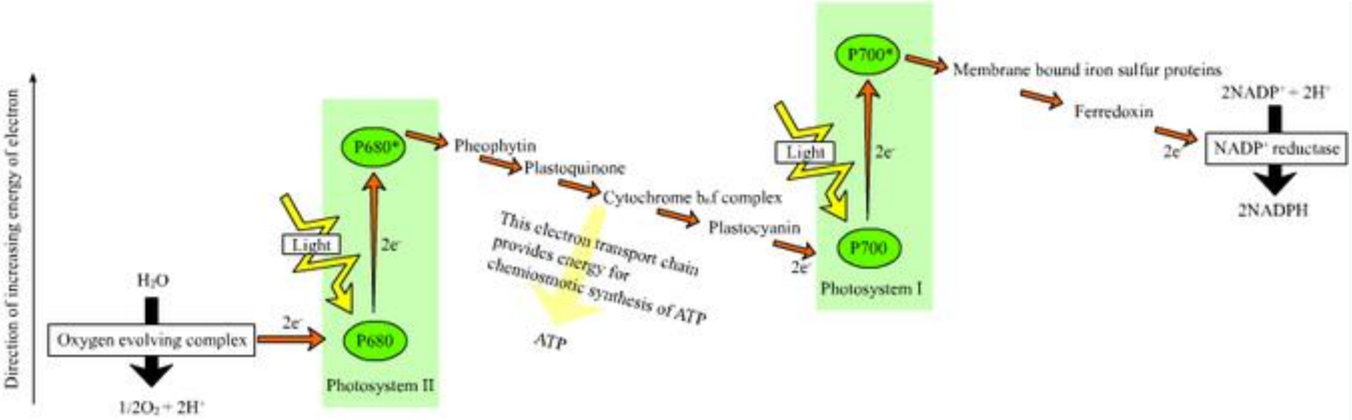
The photolysis of water (H2O) in the light reactions of photosynthesis occurs in the water-splitting complex of photosystem II embedded in thylakoid membranes of chloroplasts where light is used to split water molecules which is catalysed by presence of Mn^{+++} and Cl^- ions. When pigment system II receives light, the water molecules split into OH^- and H^+ ions. The OH^- ions unite to form some water molecules again and release O_2 and electrons. The reactions are represented by the following equations:

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

$$4H_2O \rightarrow 4H^+ + 2H_2O + O_2 + 4e^-$$

Non-cyclic electron transport or non-cyclic photophosphorylation (Z scheme): This process of electron transport is initiated by the absorption of a photon (quantum) of light by P_{700} form of chlorophyll-a molecule in pigment system I which gets excited. An electron is ejected from it and an electron deficiency or a 'hole' is left in the P_{700} molecule. The ejected electron is trapped by FRS (Ferredoxin reducing substance) which is an unknown oxidation-reduction system. The electron is know transferred to a non-heme iron protein called ferredoxin (Fd). Then the electron is transferred to reduce $NADP^+$.

When a photon (quantum) of light is absorbed by P_{680} form of chlorophyll, a molecule in pigment system II, it gets excited and an electron is ejected from it so that an electron deficiency or a 'hole' is left behind in the P_{680} molecule. The ejected electron is trapped by a compound of unknown identity usually designated by ‘Y’ or ‘Q’. This unknown compound forms oxidation-reduction system. From ‘Y’ the electron passes through a series of compounds consisting of plastoquinone (PQ), cytochrome b_{559}, cytochrome f and plastocyanin (PC). At one place during the electron transport i.e. between cytochrome b and cytochrome f, there is enough change in free energy which allows phosphorylation of one molecule of ADP to form one ATP molecule.



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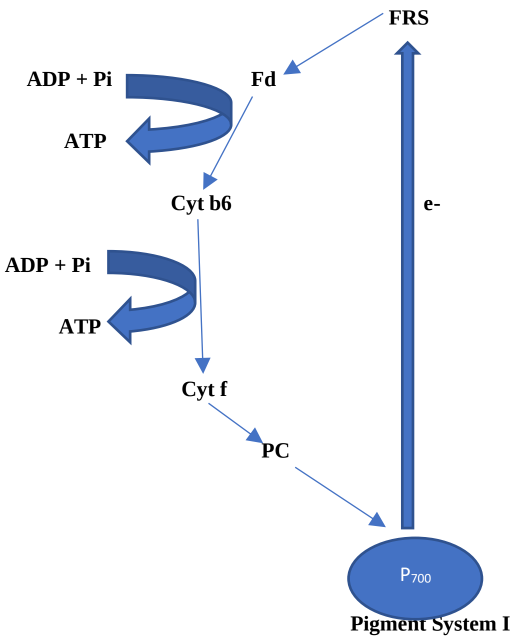
The ‘hole’ of pigment system I has been filled by the electron coming from pigment system II and the electron deficiency of pigment system has been overcome with the help of electron released during photolysis of water. In the above scheme the ejected electrons from pigment system I and II have been utilized for the reduction of $NADP^+$ and filling the electron deficiency of pigment system II respectively and never come back to the original sites. Therefore, this electron transport has been called as non-cyclic electron transport and accompanying photophosphorylation as non-cyclic photophosphorylation. The non-cyclic electron transport takes the shape of ‘Z’ hence, it is also called as Z-Scheme’.

Cyclic electron transport or cyclic photophosphorylation: The cyclic electron transport involves only pigment system I. When P_{700} molecule is excited in pigment system I by absorbing a photon of light, the ejected electron is captured by ferredoxin via FRS. Other intermediate electron acceptor which include cytochrome b_6, cytochrome f and ultimately plastocyanin which is copper containing protein lastly release the electron to original site i.e. the ‘hole’ of pigment system I and thus forming a cyclic transfer of electron. At two places during this electron transport, i.e. between ferredoxin and cytochrome b_6 and between cytochrome b_6 and cytochrome f enough energy is released for ATP synthesis. Thus, the outcome of this cycle is the formation of two energy reach ATP



C3 Cycle/ Calvin cycle/ Reductive pentose phosphate cycle/ Blackman reaction: The Calvin cycle was first investigated by Melvin Calvin. Calvin cycle may be explained by dividing it into two subheadings:

a) Synthesis of carbohydrate and
b) Regeneration of ribulose diphosphate.

Synthesis of carbohydrate:

i) Carbon dioxide is first accepted by ribulose 1,5-diphosphate and forms an unstable 6-carbon compound from which two molecules of 3-phosphoglyceric acid are formed with the help of the enzyme carboxydismutase or RuDP carboxylase (Rubisco).

ii) 3-phosphoglycric acid is reduced to 3-phosphoglyceraldehyde in presence of triose phosphate dehydrogenase.

iii) Some of the molecules of 3-phosphoglyceraldehyde isomerise into dihydroxyacetone phosphate, both of which then unite in presence of enzyme aldolase to form fructose 1,6-diphosphate.

iv) Fructose 1,6-diphosphate is converted into Fructose 6-phosphate in the presence of phosphatase.

v) Some of the Fructose 6-phosphate is converted into glucose, sucrose and starch.

Regeneration of ribulose diphosphate:

vi) 3-phosphoglyceraldehyde reacts with fructose-6-phosphate in the presence of enzyme transketolase to form erythrose-4-phosphate and xylulose-5-phosphate.

vii) Erythrose-4-phosphate combines with dihydroxyacetone phosphate in the presence of the enzyme aldolase to form sedoheptulose 1,7-diphosphate.

viii) Sedoheptulose 1,7-diphosphate is converted to sedoheptulose-7-phosphate in presence of phosphatase.

ix) Sedoheptulose 7-phosphate reacts with 3-phosphoglyceraldehyde in presence of transketolase to form xylulose-5-phosphate and ribose-5-phosphate.

x) Xylulose-5-phosphate is converted to ribulose-5-phosphate in presence of phosphoketopentose epimerase.

xi) Ribose-5-phosphate is catalysed by phosphopentose isomerase to form ribulose-5-phosphate.

xii) Ribulose-5-phosphate is finally converted into ribulose 1,5-diphosphate in the presence of phosphopentose kinase and ATP.

The first stable product of the cycle is 3-phosphoglyceric acid, a 3-carbon containing compound, so, the cycle is also known as C_3 cycle.

C4 cycle/ Hatch and Slack cycle/ C4-Dicarboxylic acid pathway/ Cooperative photosynthesis/ β-carboxylation pathway: Various steps of Hatch-Slack pathway which involves two carboxylation reactions, one taking place in chloroplasts of mesophyll cells and another in chloroplasts of bundle sheath cells.

i) CO_2 is introduced by the carboxylation of phosphoenolpyruvate in chloroplasts of mesophyll cells to form oxaloacetate. The reaction is catalysed by phosphoenol pyruvate carboxylase.

ii) The oxaloacetate is readily converted into malate or aspartate depending upon species in the presence of $NADP^+$ specific malate dehydrogenase and transaminase respectively.

iii) Malate is then transported to the chloroplasts of bundle sheath where it is decarboxylated by NADP specific malate dehydrogenase to produce pyruvic acid and CO_2

iv) The released CO_2 is used in the carboxylation of ribulose 1,5-diphosphate in presence of carboxydismutase to produce phosphoglycerate, the first stable product of Calvin cycle and thereby continue the further steps to produce starch and to regenerate ribulose 1,5-diphosphate.

v) Simultaneously, the pyruvate is transported back to the chloroplast o mesophyll cells where it is reconverted into the phosphoenolpyruvate by utilizing energy of ATP of light phase in the presence of enzyme pyruvate phosphate dikinase.

CAM plants/ Crassulacean acid metabolism/ Dark CO_2 fixation: Certain non-halophytic succulents and semi-succulent plants belonging to Crassulaceae, Cactaceae, Orchidaceae, Liliaceae, Euphorbiaceae etc. show diurnal pattern of organic acid formation. All such plants are called Crassulacean acid metabolism plants (CAM plants).

i) During night, when the stomata are open, CO_2 from the air diffuse into the leaf cells and is absorbed by phosphoenol pyruvic acid (PEP), leading to the formation of oxaloacetic acid.
ii) The oxaloacetic acid subsequently converted into malic acid by enzyme malic dehydrogenase.
iii) During day time, malic acid moves out of the cell sap into the cytoplasm where it is decarboxylated by NADP, resulting in the release of CO_2 and production of pyruvic acid.
iv) The released CO_2 combines with RuDP and enters the C_3 Calvin cycle, leading to the formation of PGA, sugar and starch.
v) The pyruvic acid thus formed, first phosphorylated into PEP which enter a chain of reactions leading to the formation of triose phosphate, hexose phosphate and starch.
vi) PEP is later regenerated from starch during night and acts as the acceptor of atmospheric CO_2.

Photorespiration and glycolytic metabolism (C_2 cycle): Krotkov (1963) coined the term photorespiration to refer “the release of carbon di oxide in respiration in presence of light”. Photorespiration occurs only in green cells of plants and has been rarely reported in tropical grasses. The photorespiration is accomplished in 3 different cell organelles which include chloroplasts, peroxisomes and mitochondria. The various steps of glycolate metabolism are as follows-

i) Under conditions of high O_2/CO_2 ratio the enzyme Ribulose biphosphate oxygenase instead of RuDP carboxylase present in the chloroplast reacts with O_2, one molecule of phosphoglycerate and one molecule of phosphoglycolate are formed Ribulose biphosphate.

ii) Phosphoglycerate again enters into the Calvin cycle, while phosphoglycolate is dephosphorylatedin the presence of phosphataseto form glycolate which enters to the peroxisome from chloroplast.

iii) Enzyme glycolate oxidase converts glycolate to glyoxylate. In the reaction hydrogen peroxide is also formed which is broken down to oxygen and water by the action of catalase.

iv) Glyoxylate is then converted to glycine in the presence of enzyme glutamate glyoxylate aminotransferase.

v) Glycine is transported to mitochondria via cytoplasm. In mitochondria two molecules of glycine join to form serine with liberation of CO_2 and NH_3 with the help of serine hydroxymethyl transferase.

vi) The serine again comes back to the peroxisome where it is converted to hydroxypyruvate by serine glyoxylate amino transferase.

vii) With the help of enzyme hydroxypyruvate reductase, with $NADH_2$ hydroxypyruvate is reduced to glycerate.

viii) The glycerate thus formed enters to chloroplast where it is transformed to 3-phosphoglycerate in the presence of glycerate kinase and enters the Calvin cycle and forms glucose.

Since glycolate and some other metabolites are 2-C compounds, the glycolate metabolism or glycolate cycle is also called C_2- cycle.