inside the thylacoids. In the light reaction, water is split into electrons, hydrogen and oxygen. The energy released during this process is used to synthesize ATPs. The ATPs are used in the subsequent *dark reaction*.

The thylacoids of the photosynthetic cells contain two kinds of photosystems (pigment systems), namely ***photosystem II*** and ***photosystem I.*** Each photosystem contains a combination of pigments like chlorophyll a,b,c, carotenoids, etc. Photosystem I contains larger proportion of chlorophyll 'a' than photosystem II. Each photosystem has a ***reactive molecule.***

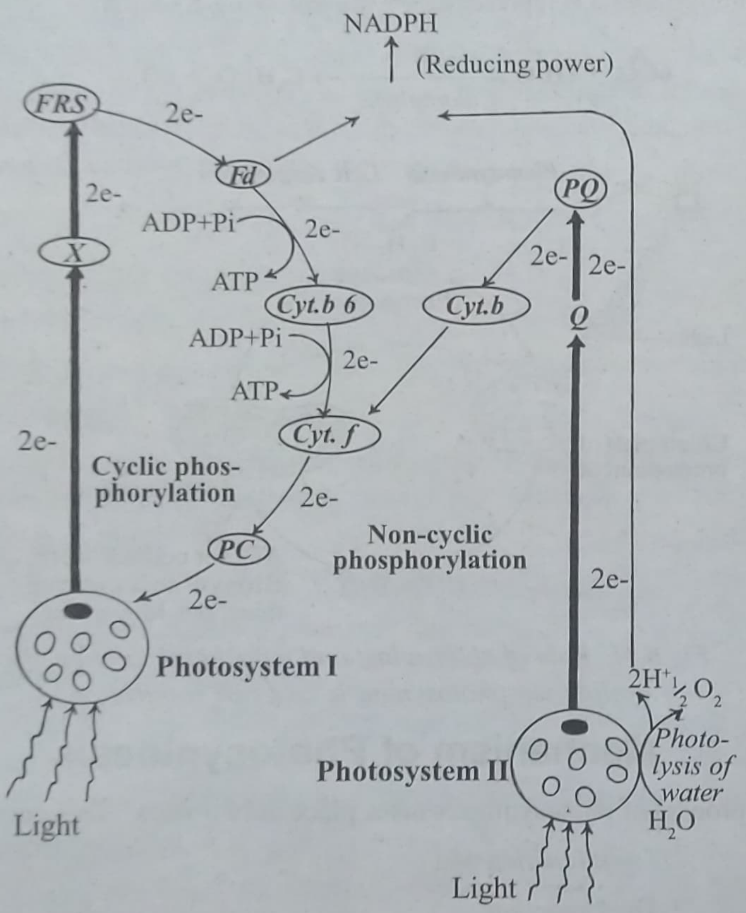

Fig.8.12: Schematic representation of light reaction of photosynthesis. X-an unknown electron acceptor, FRS-ferredoxin reducing substance, Fd-ferredoxin, Cyt.b6-Cytochromeb6, Cyt.f-Cytochrome f, Pc-Plastocyanin, Q-an intermediate electron acceptor, and PQ plastoquinone.

The light energy first enters the pigment system II. At that time, the water is split into protons, electrons and oxygen. This process is called ***photolysis.***

$$H_2O \xrightarrow{Light} 2e + 2H^+ + {}^1/_2\,O_2$$

The electrons released in the splitting of water are accepted by the ***reactive molecule*** of photosystem II. The reactive molecule of photosystem II passes the electrons to another pigment of the photosystem II called ***primary electron acceptor.*** The electrons are then transferred to the electron transport system . In the course of this passage, ***ATP*** is formed from ADP and inorganic phosphate. This process is called ***photophosphorylation*** and is comparable to phosphorylation of cell respiration.

The electron released from photosystem II is accepted by the ***reactive molecule*** of photosystem I. The electron ejected by this reactive molecule is accepted by the ***primary electron acceptor*** of photosystem I. From here the electron is passed to an electron acceptor called ***NADP.*** As the NADP receives the electrons, it is reduced to NADPH.

Thus the gain from the light reaction is the ATP molecules and the NADPH. Oxygen is a by-product. The NADPH is the chief source of the power used in dark reactions to reduce carbon dioxide into glucose.

2. Dark Reaction

The dark reaction occurs even in the absence of light and hence the name. This also occurs in the presence of light. During dark reaction, carbon is fixed. The dark reaction depends on the products of light reaction. It reduces CO_2 into carbohydrate. This process is called ***carbon fixation.*** The dark reaction takes place inside the ***stroma*** of chloroplasts.

There are two pathways in dark reaction. They are

1. *C_3 pathway or Calvin cycle and*
2. *C_4 pathway or Hatch-Slack cycle.*

1. C_3 Pathway or Calvin Cycle

The path of carbon in dark reaction was worked out by the Nobel Prize winner ***Melvin Calvin.*** Hence it is called ***Calvin cycle.*** As the 3-carbon compound 3-phosphoglyceric acid is the first stable product in this cycle, it is commonly called ***C_3 pathway.*** The important steps in this pathway are given below:

1. Carboxylation: A five carbon sugar ***Ribulose diphosphate,*** already present in the stroma, accepts CO_2 to form an unstable ***6-carbon intermediate compound.***

The enzyme ***RDP carboxylase*** catalyses this reaction. In this way, 6 molecules of intermediate compound are formed.

2. Splitting: Each 6-carbon compound combines with H_2O and readily splits into two molecules of 3-carbon compounds, ***3-phosphoglyceric acids.*** The enzyme ***carboxydismutase*** catalyzes this reaction. Thus 12 molecules of 3-phosphoglyceric acid are formed.

3. Phosphorylation: Each 3-phosphoglyceric acid reacts with ATP in the presence of an enzyme ***phosphoglyceric acid kinase*** to form ***diphosphoglyceric acid.*** Thus 12 diphosphoglyceric acid molecules are formed.

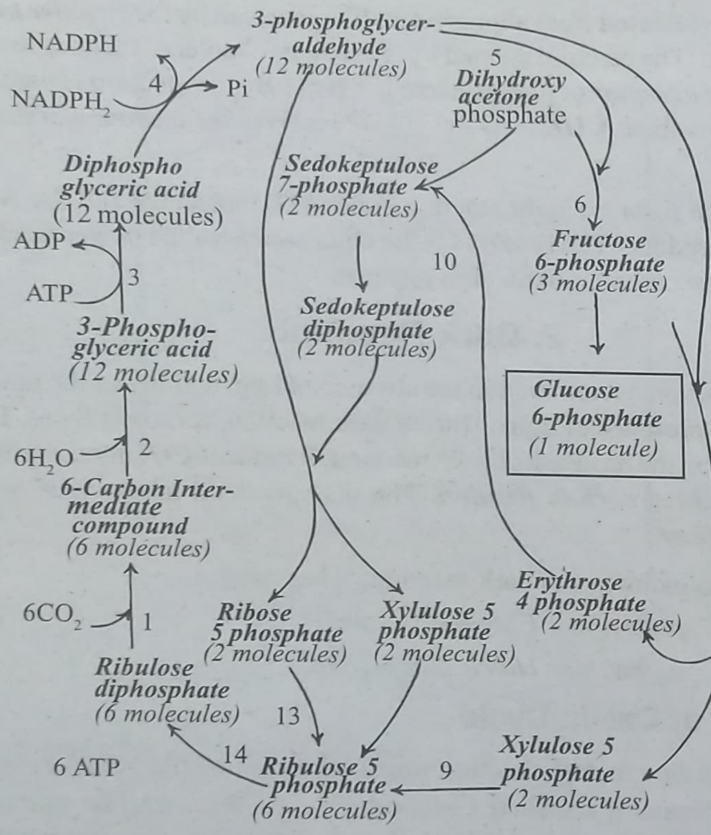

Fig.8.13: Calvin Cycle.

4. Reduction: In the presence of the enzyme ***triose phosphate dehydrogenase,*** the diphosphoglyceric acid accepts hydrogen from $NADPH_2$ and loses an inorganic phosphate. This produces ***3-phosphoglyceraldehyde.*** Thus 12 molecules are formed.

5. Glucose Formation: In the presence of the enzyme ***isomerase,*** 5 molecules of 3-phosphoglyceraldehyde are converted into ***dihydroxyacetone phosphate.*** Of the 5 molecules, 3 molecules combine with 3-molecules of 3-phosphoglyceraldehyde (Step-4) in the presence of ***aldolase*** to form 3-molecules of ***fructose diphosphate.*** (Not shown in the diagram). These fructose diphosphates undergo dephosphorylation to form 3 molecules of ***fructose 6-phosphate.*** Of these, one molecule becomes isomerised into a ***glucose 6-phosphate molecule.*** Other sugars are made from this glucose phosphate.

6. Regeneration of Ribulose diphosphate: Fructose 6-phosphate reacts with 3-phosphoglyceraldehyde to form ***erythrose 4 phosphate*** and ***xylulose 5-phosphate*** by the action of the enzyme ***transketolase***. Thus two molecules of erythrose 4-phosphate and two molecules of xylulose 5-phosphate are formed. The enzyme ***pentose kinase epimerase*** converts the xylulose 5-phosphate into ***ribulose 5-phosphate.***

The erythrose 4-phosphate reacts with dihydroxy acetone phosphate in the presence of ***aldolase*** to form ***sedokeptulose diphosphate***. Thus two sedokeptulose diphosphates are formed. They undergo dephosphorylation to form ***sedokeptulose 7-phosphate.*** Each sedokeptulose 7-phosphate reacts with 3-phosphoglyceraldehyde to form a ***ribose 5-phosphate*** and ***xylulose 5-phosphate.*** The enzyme ***transketolase*** catalyses this reaction. Thus two ribose 5-phosphates and two xylulose 5-phosphates are formed.

The enzyme ***phosphoketopentose epimerase*** converts the xylulose 5-phosphates into 2 molecules of ***ribulose 5- phosphate.*** Another enzyme ***phosphopentose isomerase*** converts the ribose phosphates into ***ribulose 5-phosphates.*** Thus 6 molecules of ribulose 5-phosphates are regenerated.

Each of these ribulose 5-phosphates in the presence of ***phosphopentokinase*** reacts with a ATP to form ***ribulose diphosphate.*** These ribulose diphosphates are ready to accept new CO_2 molecules to reduce them into sugar.

2. C_4 Pathway or Hatch-Slack Cycle

The C_4 pathway was worked out by two Australian workers ***M.D. Hatch*** and ***C.R. Slack*** in 1966. Hence, it is also called ***Hatch-Slack cycle***. It shows surprising biochemical adaptation in some ***tropical*** grasses, such as sugar cane, to arid climate. In the leaves of these plants, the vascular bundle is surrounded by a layer of large parenchymatous cells. This layer is called ***bundle sheath***. The chloroplasts lack grana. The ***inner vascular cells*** transport materials. The bundle ***sheath*** cells carry out carbon fixation by ***Calvin cycle***.

The outer ***mesophyll cells*** can trap atmospheric CO_2 even in very low concentrations.

There are only four steps in Hatch-Slack cycle.

1. **Carboxylation:** In the mesophyll chloroplasts, the 3-carbon compound ***phosphoenol pyruvate*** picks up CO_2 and becomes ***oxaloacetate,*** a 4-carbon compound. The enzyme ***phosphoenol pyruvate carboxylase*** (***PEP*** carboxylase) catalyzes the reaction.

2. **Break Down:** Oxaloacetate breaks down readily into 4-carbon ***malate*** and ***aspartate.*** The aspartate is converted into malate. The malate diffuses from the mesophyll cells into the bundle sheath cells through plasmodesmata.

3. **Splitting:** In the bundle sheath cells, malate and aspartate split up enzymatically to yield free CO_2 and 3 carbon compound ***pyruvate.*** The CO_2 is used in Calvin cycle in the bundle sheath cells.

4. **Phosphorylation:** The pyruvate diffuses back into the mesophyll cells. Pyruvate receives a phosphate from ATP and becomes ***phosphoenol pyruvate***. The phosphoenol pyruvate is ready to accept another molecule of CO_2. Thus the cycle continues.

The C_4 pathway helps the plants to use much CO_2 from the atmosphere, even if the CO_2 level is very low in the atmosphere.