Chapter -11: Photosynthesis in Higher Plants

Early experiments relating to photosynthesis. Photosynthesis as a means of autotrophic nutrition: Site of photosynthesis, Pigments involved in photosynthesis(elementary idea) ,Photochemical and biosynthetic phases of photosynthesis, cyclic and non-cyclic photophosphorylation, chemiosmotic hypothesis; photorespiration; C3 and C4 pathways, factors affecting photosynthesis.

Early experiments relating to photosynthesis

- **Joseph Priestly:** Candle with bell jar and mouse experiment – He concluded that air is necessary for the growth of a plant. He discovered the fact that plants restore oxygen in the air.
- **Jan Ingenhousz:** Experiment with aquatic plant in light and dark – He concluded that sunlight is essential for plant processes that purify the air.
- **Julius Von Sachs:** Green parts of plant make glucose and store as starch.
- **T.W. Engelmann:** Spilt light using prism into 7 colours (VIBGYOR) - Green algae *Cladophora* placed in a suspension of aerobic bacteria - Bacteria were used to detect the sites of O_2 evolutions.
- **Cornelius van Niel:** He did experiment with purple and green bacteria and demonstrated photosynthesis is a light dependent process with hydrogen from H_2O reduces CO_2 to carbohydrates. He concluded that oxygen comes from H_2O, and not from CO_2. Finally, the correct equation for photosynthesis was discovered.

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

Photosynthesis as a means of autotrophic nutrition

- **Photosynthesis** is a physico-chemical process that uses light energy to synthesis organic compounds e.g. Glucose.
- ***Importance of photosynthesis:***
  - Primary source of food
  - Release O_2 to atmosphere

Site of Photosynthesis

- Green leaves, green stems and floral parts (sepal).
- Chloroplast - found in mesophyll cells of leaves.
- In chloroplast – the membrane system is responsible for trapping the light energy and also for the synthesis of ATP and NADPH. Where stroma has enzymes for the reduction of CO_2 into carbohydrates (Glucose).

Pigments Involved in Photosynthesis

- 4 types of pigments may be present in leaves:
    1. Chlorophyll a
    2. Chlorophyll b
    3. Xanthophylls
    4. Carotenoids
- An absorption spectrum is the graph plotted against the fraction of light absorbed by the pigment.
- An action spectrum is the rate of a physiological activity plotted against the wavelength of light.
- Photosystems are pigments that are organized in the thyllakoid membrane in to two different photosystems (**PS I & PS II**)
- Each PS has one specific chlorophyll – a, and many other accessory pigments bound by proteins.
- Chlorophyll – a forms the reaction centre (actual reaction takes place) other pigments form the light harvesting complex (LHC) called antennae.
- **PS I** reaction centre is **p700** (chlorophyll –a absorbs light at 700 nm)
- **PS II** reaction centre is **p680** (chlorophyll –a absorbs light at 680 nm)

Photochemical and biosynthetic phases of photosynthesis

Light Reaction (Photochemical Phase)

- This phase directly depends on light. The pigments absorb light energy and produce ATP.
- Includes:
    - Light absorption
    - Water splitting
    - Oxygen release
    - Formation of ATP and NADPH, which is then used in the biosynthetic phase
- Pigment molecules bound to the proteins form LHC (light harvesting complexes).

  LHC are located within two photosystems – **PS I** and **PS II**

  Each photosystem has two parts:

    - **Reaction centre** − consisting of chlorophyll a molecule
    - **Antennae** − consisting of accessory pigments, which increase the efficiency of photosynthesis by absorbing different wavelengths of light

    Reaction centre is different in both photosystems:

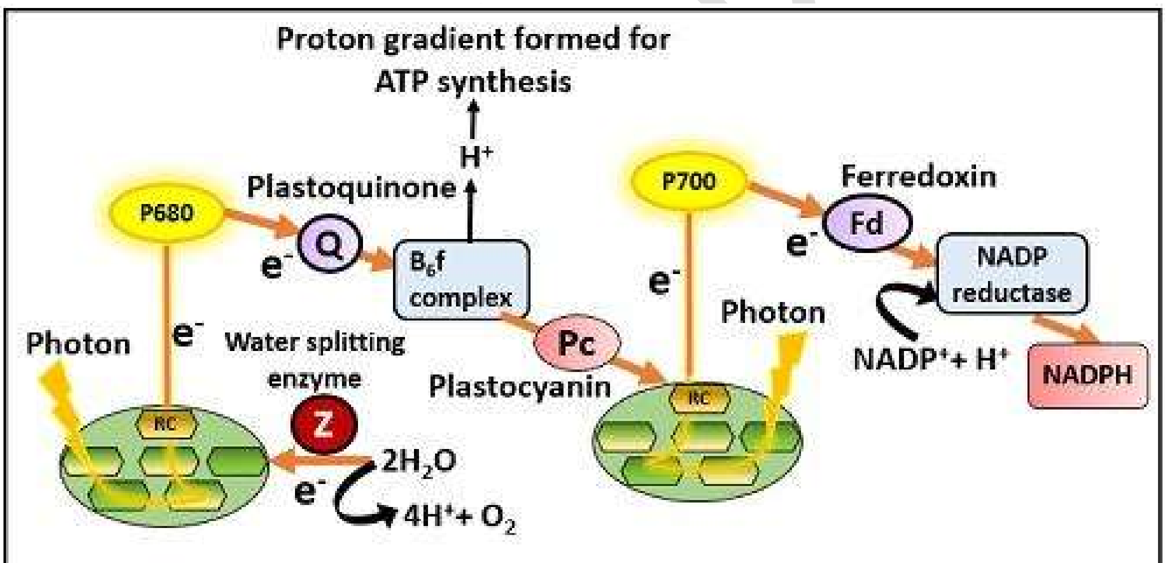
    - **PSI − P700**: Here chlorophyll a has absorption peak at 700 nm here
    - **PSII − P680**: Here chlorophyll a has absorption peak at 680 nm here.

Photo-Phosphorylation: The process of formation of ATP in chloroplast in the presence of sunlight

- Photo-phosphorylation is of two types:
    - Non-cyclic photo-phosphorylation
    - Cyclic photo-phosphorylation

Non-Cyclic Photo-Phosphorylation

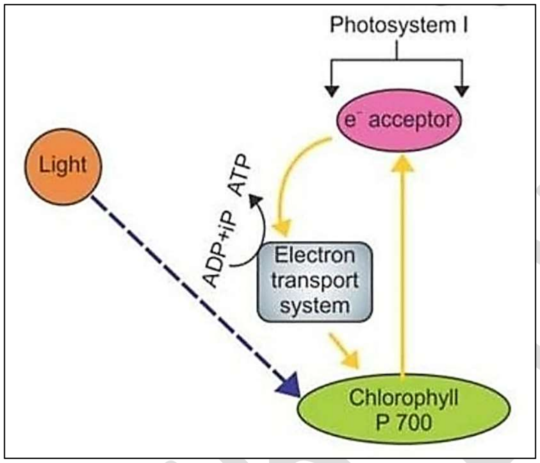
- PSII absorbs 680 nm wavelength of red light, causing electrons to become excited and these electrons are then accepted by an electron acceptor, which sends them to an electron transport system.
- Electron transport system transfers the electrons to PSI.
- Electrons in PSI are simultaneously excited on receiving a wavelength of 700 nm.
- From the electron acceptor, electrons are transferred to the molecule of NADP+.
- Addition of these electrons reduces the NADP+ to NADPH+ H+.
- Since the electrons lost by PSII do not come back to it, this process of formation of ATP is called **non-cyclic photo-phosphorylation**.



Noncyclic Photophosphorylation

Cyclic Photo-Phosphorylation

- In this scheme, only PSI is functional. Hence, the electrons are circulated within the photosystem.
- This results in a cyclic flow of electrons.
- This scheme could possibly be occurring in stroma lamellae because it lacks both
- PSII and NADP reductase enzyme.
- This cyclic flow results only in the synthesis of ATP, and not of NADPH + H+.



Non- cyclic Photophosphorylation	Cyclic Photophosphorylation
Photolysis of water takes place.	No photolysis of water occurs.
Both PS I and PS II are involved.	Only PS 1 is involved.
Electrons are not cycled.	The electrons released by PS I come back to PS I itself.
Both ATP and NADPH are produced.	Only ATP is formed.
Oxygen is liberated	Oxygen is not liberated.

Splitting Of Water

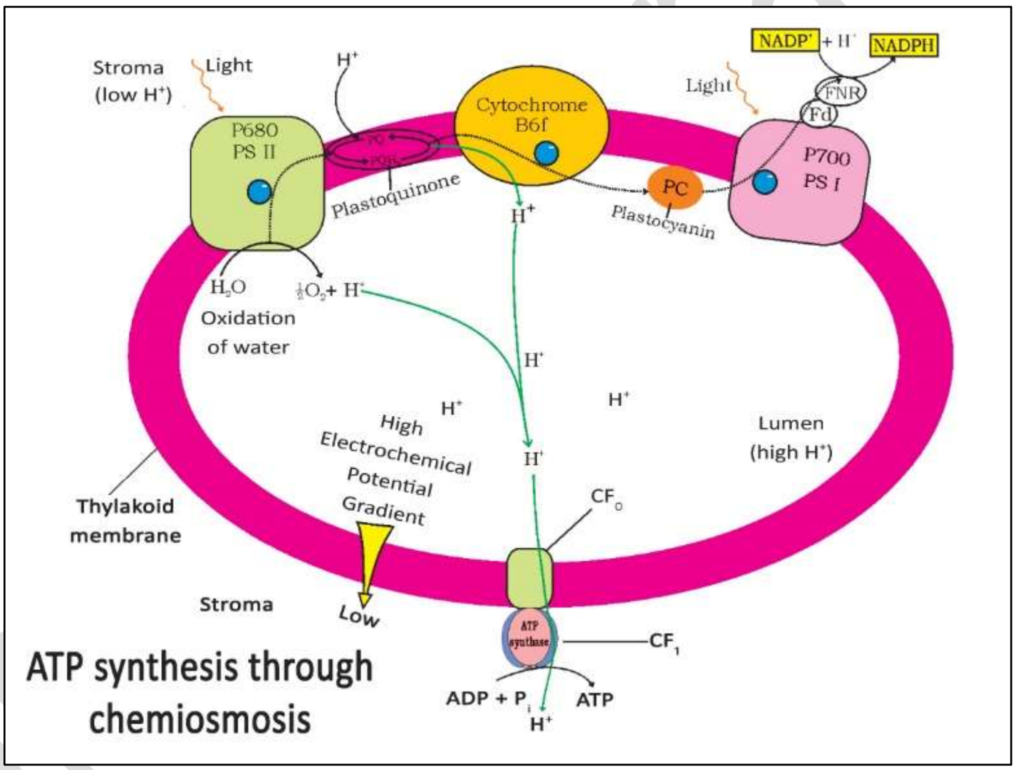
- Water splitting complex is associated with PS II.
- Manganese, chlorine, etc., play an important role.
- The light-dependent splitting of water is called photolysis

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

- Electrons formed are used for replacing the electrons lost from P680.
- P680 absorbs light and becomes as a strong oxidizing agent and splits a molecule of water to release oxygen. Oxygen is liberated as a by-product of photosynthesis.
- Protons are used for the formation of reducing power NADP to NADPH+.

Chemiosmotic Hypothesis

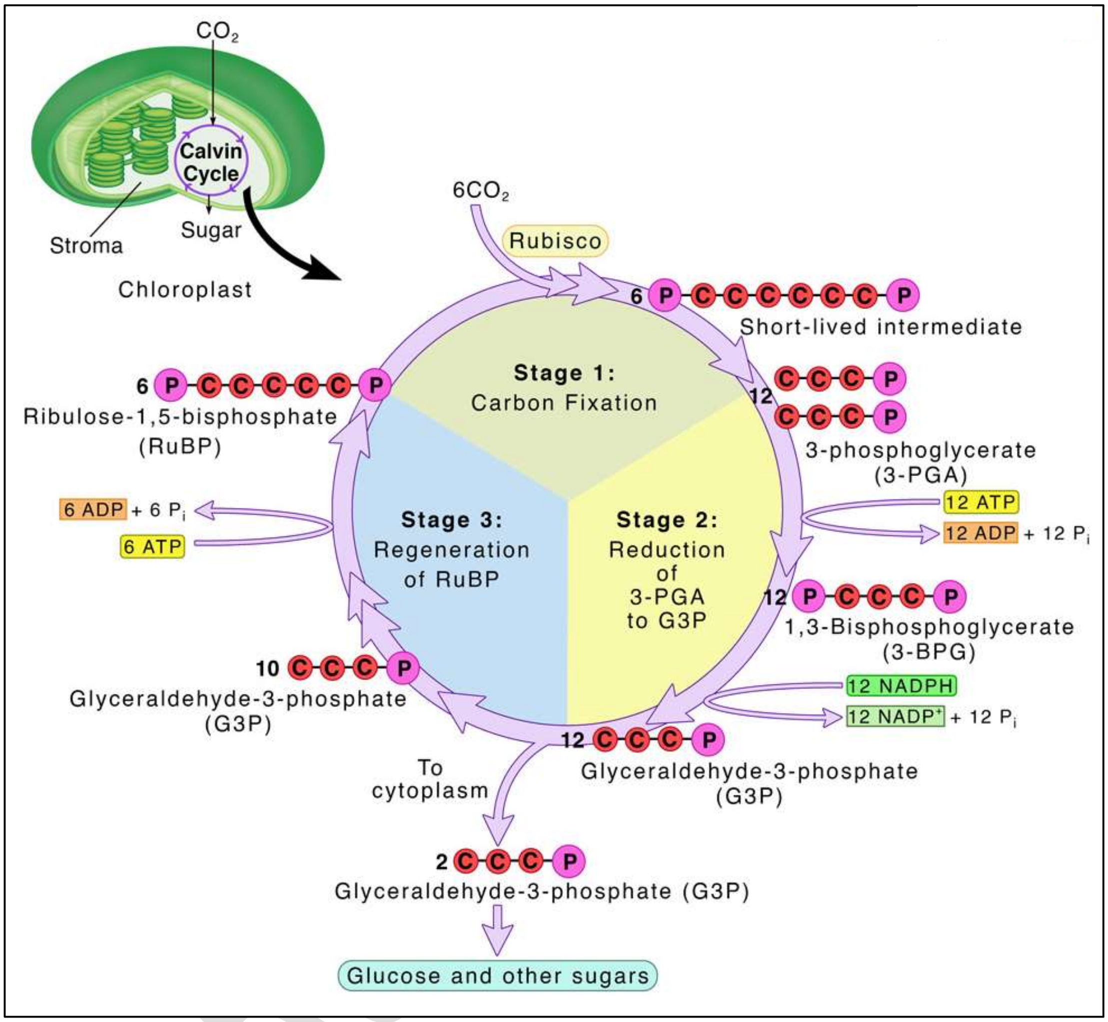
- This hypothesis was proposed by Mitchell in 1961.
- The chemiosmotic hypothesis is a theory that explains the mechanism by which ATP is synthesized during the light reactions of photosynthesis. Here's a brief pointwise explanation:
    1. Light energy excites electrons in chlorophyll during photosynthesis.
    2. Electrons move through the electron transport chain (ETC) in the thylakoid membrane.
    3. Protons are pumped across the membrane into the thylakoid lumen, creating a proton gradient.
    4. Protons flow back into the stroma through ATP synthase, driving ATP synthesis.
    5. This process, called chemiosmosis, links electron transport to ATP production.



Dark Reaction / Biosynthetic Phase:

- Next stage is the biosynthetic phase. In this, ATP and NADPH are used for synthesising the food / Glucose.
- This stage is also called the dark phase as it is independent of light.
- It takes place in the stroma of chloroplasts.
- In some plants, the first product of CO_2 fixation is a 3-carbon compound called 3- phosphoglyceric acid (PGA). These plants are said to adopt the C3 pathway.
- In other plants, the first CO_2 fixation product is a 4-carbon compound called oxaloacetic acid. These plants are said to adopt the C4 pathway.

Calvin Cycle (C3 Cycle)



- The path of carbon in the dark reaction was traced by Melvin Calvin using radioactive carbon (14C).
- The primary acceptor of CO_2 was found to be a 5-carbon ketose sugar called Ribulose bisphosphate (RuBP). RuBP is used in a cyclic manner (regenerated) and a sugar is synthesised.

3 phases of Calvin cycle: Carboxylation, Reduction and Regeneration of RuBP

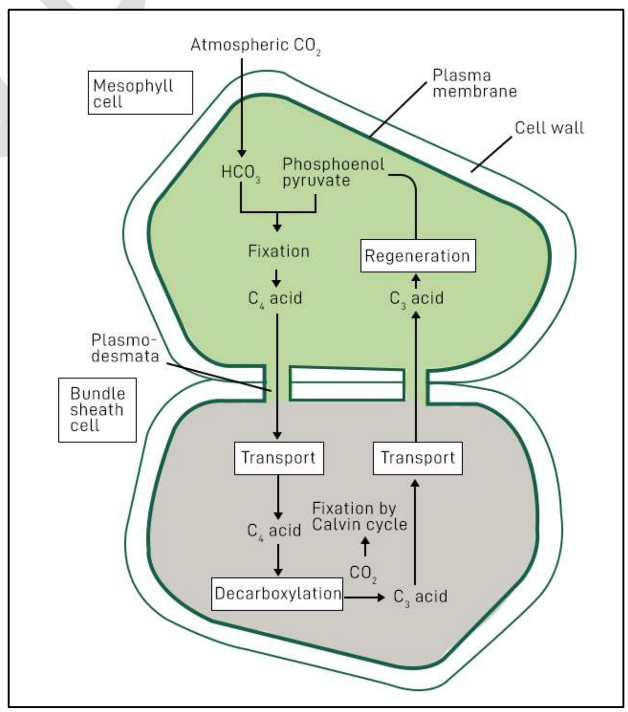
1. **Carboxylation:**
   - Ribulose 1, 5-bisphosphate combines with CO_2, and fixes it to a stable organic intermediate 3C compound called 3-phosphoglycerate (2 molecules). 3 PGA is the first stable product of this cycle.
   - Reaction catalysed by the enzyme RuBisCO (RuBP Carboxylase-Oxygenase)

2. **Reduction**:
   - Here, two molecules each of ATP and NADPH are required for fixing one molecule of CO_2.
   - This stage contains a series of reactions.
   - Glucose is formed as a result of this series of reactions.

3. **Regeneration:**
   - RuBP regenerates to enable the cycle to continue uninterrupted.
   - 1 ATP molecule is required.

- For the formation of one molecule of glucose, six molecules of CO_2 need to be fixed; hence, six cycles are required.
- **ATP required:**
  - ✓ For fixing 1 molecule of CO_2 − 3 (2 for reduction and 1 for regeneration)
  - ✓ For fixing 6 molecules of CO2 − 3 × 6 = 18 ATP
- **NADPH required:**
  - ✓ For fixing 1 molecule of CO2 − 2 (for reduction)
  - ✓ For fixing 6 molecules of CO2 − 2 × 6 = 12 NADPH
- Thus, the synthesis of 1 molecule of glucose requires 18 ATP and 12 NADPH.

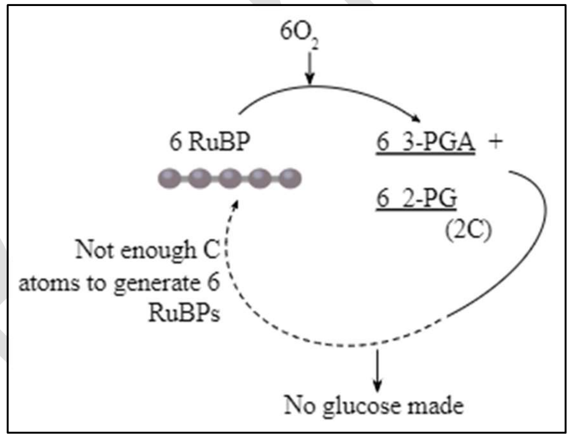
C4 Pathway (Hatch and Slack Pathway)



- Occurs in plants like maize, sugarcane − plants adapted to dry tropical regions.
- The leaves of C4 plants have Kranz anatomy. These plants show 2 types of photosynthetic cells, mesophyll cells and bundle sheath cells. Chloroplasts are dimorphic i.e., those in the mesophyll cells are granal and in bundle sheath cells are agranal.
- C4 plants can tolerate high temperature and high light intensity, show greater productivity of biomass, and lack photorespiration.
- Primary CO_2 acceptor: Phosphoenol pyruvate (PEP) − a 3-carbon molecule.
- PEP Carboxylase fixes CO_2 in the mesophyll cells. It forms the 4-carbon compound oxaloacetic acid (OAA), and then other 4-carbon compounds Malic acid.

- These compounds are transported to the bundle sheath cells. There, C4 acid breaks down to form C3 acid and CO_2, and carbon dioxide enters the C3 cycle).
- C3 acid, so formed, is again transported to the mesophyll cells and regenerated back into PEP.
- C3 cycle cannot directly occur in the mesophyll cells of C4 plants because of the lack of the enzyme RuBisCO in these cells.
- RuBisCO is found in abundance in the bundle sheath cells of C4 plants.

Photorespiration



- It is a process in which there is no formation of ATP or NADPH, but there is utilization of ATP with release of CO2. It is also considered a wasteful process.
- Photorespiration is responsible for the difference between C3 and C4 plants.
- At high temperature and high oxygen concentration, In C3 plants, RuBP carboxylase function as oxygenase.
- RuBP oxidized into phosphoglycerate (3C) and phosphoglycolate (2C)
- 75% of carbon lost during oxygenation of RuBP
- There is loss of photosynthetically fixed carbon and no energy rich compounds are formed, so photorespiration is a wasteful process.

C3 Pathway	C4 Pathway
RuBisCO catalyzes the fixation of CO2	PEP carboxylase catalyzes the fixation of CO2
3-phosphoglycerate (3-PGA)	Oxaloacetate (OAA)
No spatial separation of carbon fixation and Calvin cycle reactions	Spatially separates carbon fixation and Calvin cycle reactions
Lower CO2 concentration in bundle sheath cells	Higher CO2 concentration in bundle sheath cells
Less efficient due to photorespiration	More efficient due to reduced photorespiration
Most plants, including wheat, rice, and soybeans	Certain grasses such as maize, sugarcane, and sorghum, as well as some desert plants
No distinct Kranz anatomy	Distinct Kranz anatomy with bundle sheath and mesophyll cells

Factors affecting rate of Photosynthesis:

Blackmans law of limiting factors.

- When a physiological process is controlled by a number of factors, the rate of reaction depends on the lowest factor, so the factor which is the least/ limiting will determine the rate of Photosynthesis.

Photosynthesis is influenced by internal (plant) factors and external factors.

- The internal factors include number, size, age and orientation of leaves, mesophyll cells and chloroplasts, internal CO_2 concentration and amount of chlorophyll.
- The external factors include Light, Temperature, CO_2 concentration, Water.

1. **Light.**
   - Quality and intensity of light
   - Wavelength of light between 400 nm 700 nm is called photosynthetically active radiation (PAR).
   - High intensity of light destruct chlorophylls.
2. **Temperature.**
   - High temperature denatures enzymes of biosynthetic phase and low temperature inactivates enzyme activity reducing photosynthetic rate.
3. **Carbon dioxide concentration.**
   - In C3 plants upto 500 and in C4 plants upto 360
4. **Availability of water.**
   - Less water leads to - water stress, stomata closes, less carbon dioxide, reduce leaf expansion and less photosynthetic area.