6. Photosynthesis

- **Photosynthesis**
    - The process by which green plants make their own food is called photosynthesis.
    - Photosynthesis is the process in which green plants synthesise food in the form of carbohydrate from carbon dioxide and water, utilizing solar energy.
    - $6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$
    - The oxygen is evolved from the splitting of water while glucose is formed by reduction of carbon-dioxide.
    - Chlorophyll is the green pigment found in the chloroplasts.
    - The chlorophyll pigments trap the photons of light and get excited and thus initiate the process of photosynthesis.

- **Major contribution in the process of photosynthesis**
    - Joseph Priestley – Found out the role of air in the growth of green plants
    - Jan Ingenhousz – Showed that sunlight is essential for the plant processes
    - Julius von Sachs – Showed evidence that plants produce carbohydrates when they grow
    - T.W. Engelmann – Described the first action spectrum of photosynthesis
    - Cornelius van Neil – Proved that oxygen evolved during photosynthesis comes from water

- **Site and phases of photosynthesis**
    - Photosynthesis takes place in chloroplasts.
    - The light phase of photosynthesis takes place in grana.
    - Light reaction is called so because the reaction is light driven.
    - The dark phase of photosynthesis takes place in stroma part of chloroplast.
    - Dark reaction is indirectly dependent on light as during dark reaction, the energy produced (during light reaction) is used.

- **Light Reaction**
    - Also called photochemical phase
    - Includes following steps:
        - Absorption of light by chlorophyll molecules
        - Splitting of water
        - Formation of ATP and NADPH2
    - Light reaction involves two pigment systems called PS I and PS II.
    - Photosystem I (PS I) – It is the reaction centre having an absorption peak at 700 nm (P700).
    - Photosystem II (PS II) – It is the reaction centre having an absorption peak at 680 nm (P680).

- **Electron transport**
    - Z scheme of light reaction involves:

Absorption of light by light harvesting complexes in PS II

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Excitation of electrons (e^-)

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Transfer of e– from PS II to e^- acceptor

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Transfer of e– from acceptor to PS I through an electron transport chain

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Excitation of electrons (e^-) in PS I

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Transfer of e^- to another e^- acceptor

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Reduction of $NADP^+$ to NADPH $^+$ H^+

- P680 (PS II) is directly involved with photolysis of water, thereby producing oxygen and electrons as by-products
- Electrons from PS II are utilized by PS I for reduction of $NADP^+$

- **Photo - phosphorylation**
    - Photo-phosphorylation is the production of ATP in the presence of light energy.
    - Two types of photo-phosphorylation:
- **Cyclic photo-phosphorylation**
    - Cyclic process and involves only PS II photosystem
    - Synthesis of ATP only
- **Non-cyclic photophosphorylation**
    - Non-cyclic process and involves both PS I and PS II photosystem
    - Synthesis of both ATP and NADPH $^+$ H^+

Chemiosmotic hypothesis

- It states that ATP synthesis is linked to development of proton gradient across thylakoid membrane.
- Chemiosmosis requires a membrane, a proton pump, a proton gradient and ATPase.

- **Proton gradient develops because of the following reasons:**

- Splitting of water on the inner side of membrane that releases H^+ in the lumen.
- When electron carriers present outside the membrane pass on their electrons to the electron carriers present inside during photo-phosphorylation.
- Removing of protons from stroma and transferring them to lumen for the reduction of $NADP^+$ to NADPH $^+$ H^+ by the enzyme NADP reductase.

ATPase: This enzyme has two parts

- F_0– embedded in the membrane and carry out facilitated diffusion of H+
- F_1– protrudes towards the stroma
- Conformational changes occur in the F_1 particle of the ATPase that helps it to synthesise ATP molecules.

- **Dark reaction**
  - Reduction of CO_2 to form carbohydrate
  - It involves two cycles: Calvin cycle (C_3 cycle) or C_4 pathway
- **Calvin cycle**
  - It involves 3 steps – carboxylation, reduction, and regeneration.
  - The primary CO_2 acceptor is ribulose 1, 5 bisphosphate.
  - The first stable product is 3-phosphoglycerate.
  - Enzyme involved is RuBP– carboxylase – oxygenase or RuBisCo.
  - Calvin cycle fixes one CO_2 in one cycle. Therefore, $6CO_2$, along with 18 ATP and 12 NADPH, are required to make one glucose molecule.
  - Six turns of Calvin cycle are required to produce one molecule of glucose.

- **C4 pathway [Hatch and Slack pathway]**
  - Maize and sorghum are examples of plants that undergo C4 pathway.
  - C4 plants show Kranz anatomy to prevent photorespiration and show carbon fixation through Hatch and Slack pathway.
  - The primary CO2 acceptor in C4 cycle is phosphoenol pyruvate.
  - The 1st stable product formed in C4 cycle is oxaloacetic acid.
  - The enzyme involved in CO2 fixation in C4 cycle is PEP carboxylase present in mesophyll cells.
  - Mesophyll cells lack RuBisCo enzyme.
  - Bundle sheath cells have an abundance of Ribulose bisphosphate carboxylase enzyme, but lack PEP carboxylase.

Photorespiration

- It occurs in chloroplast, peroxisomes, and mitochondria.
- Under high concentration of oxygen, RuBP carboxylase acts as RuBP oxygenase and breaks Ribulose 1, 5 bisphosphate into 2 – phosphoglycolic acid.
- Since some O_2 binds with the RuBisCO in C_3 plants, hence CO_2 fixation is decreased.
- This pathway does not involve the synthesis of ATP or NADPH. Hence, it is a wasteful process.Photorespiration

(i) Crassulacean acid metabolism is also known as CAM photosynthesis.
(ii) This pathway was first observed in the plants of the family Crassulaceae, which includes stonecrops and fleshy plants (succulents).
(iii) In CAM plants, stomata open at night to collect carbon dioxide and remain closed during the daytime to conserve moisture.
(iv) During the night, the CO_2 taken in by the leaves gets fixed and forms malic acid.
(v) Malic acid, thus formed, gets stored in the vacuoles of mesophyll cells and is used as a source of CO_2 during the daytime to carry out photosynthesis via the C_3 pathway.
(vi) Thus, the CAM pathway is a kind of adaptation that allows succulent plants to carry out the process of photosynthesis with minimal loss of water.

- **Factors affecting photosynthesis**

- Several factors such as light, CO_2, temperature, and water affect the process of photosynthesis.
- **Law of Limiting Factors (Stated by Blackman) -** The Blackman's law of limiting factors states that when a chemical process is affected by more than one factor, then its rate will be determined by factor which is nearest to its minimal value (factor which directly affects the process if its quantity is changed).
- **Light –** There is a linear relationship between incident light and rate of photosynthesis at low light intensities. While the rate does not increase further at higher light intensities (as other factors become limiting).
- **Carbon dioxide –** It is the major limiting factor. Concentration of CO_2 upto 0.05% increases the rate of photosynthesis. However, beyond this value, it is harmful.
- **Temperature –** The rate is maximum at an optimum temperature, which differs in different plants.
- **Water –** Water is the main reactant in the process of photosynthesis and its scarcity affects a lot.