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NEET2025

BIOLOGY NOTES

BOTANY

Photosynthesis in Higher plants

PHOTOSYNTHEIS IN HIGHER PLANTS

Photosynthesis:

- Photosynthesis is an enzyme regulated anabolic process of manufacture of organic compounds inside the chlorophyll containing cells from CO_2 and H_2O with the help of sunlight.
- It can be divided into 2 phases:

  1) Photochemical phase 2) Biosynthetic phase

Early Experiments on Photosynthesis:

→ Joseph Priestly (1733 – 1804) in 1770 performed a series of experiments that revealed the essential role of air in the growth of green plants by Bell Tar experiments.

- He also discovered oxygen in 1774.

→ Jan Ingelhousz (1779) has concluded that purification of air was done by green plants part only and that too in the presence of sunlight.

- In another experiment with an aquatic plant, he showed that in bright sunlight, small bubbles were formed around the green parts while in the dark they did not. Hence he showed that it is only the green part of the plants that could release O_2.

→Julius Von Sachs (1854) provided evidence for production of glucose in chlorophyll located chloroplasts within plant cells and glucose is usually stored as starch.

→ T.W. Engelmann (1843 – 1909) used a prism splitted light into its spectral components and then illuminated a green algae, cladophora placed in a suspensions of aerobic bacteria, which were used to direct the site of O_2 evolution.

→ Cornelius Van Niel (1930) demonstrated that photosynthesis is essentially a light-dependent reaction in which hydrogen from a suitable oxidizable compound reduces carbon dioxide to carbohydrates.

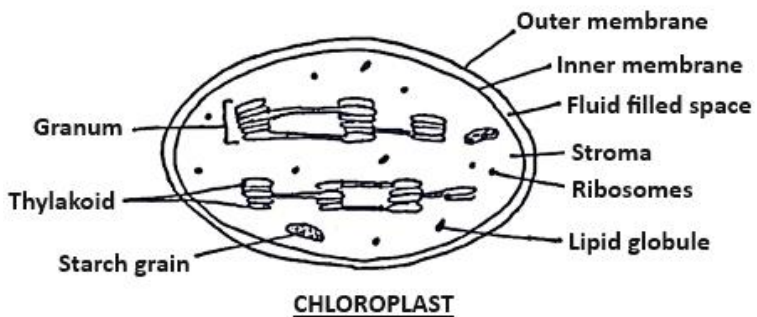
- It was inferred that the O_2 evolved from H_2O not from carbon dioxide.

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

→ Moll's half leaf experiment proved that CO_2 is necessary for photosynthesis in leaf.

Photochemical Phase:

Site of Photosynthesis:



CHLOROPLAST

- Mesophyll cells in the leaves, have a large number of chloroplast which align themselves along the walls of the mesophyll cells, such that they get the optimum quantity of the incident light.
- Chloroplasts are double membrane bound organelles, within the chloroplasts there is the membranous system consisting of grana the stroma lamellae and the fluid stroma.
- The membrane system is responsible for trapping the light and also for the synthesis of ATP and NADPH.
- In stroma enzymatic reactions incorporate CO_2 into the plant leading to the synthesis of sugar (starch).
- The set of reactions directly driven by light is called light reaction.
- The reactions which are not directly light driven but are dependent on the products of light reactions (ATP & NADPH) are known as dark reactions.

Pigments involved in photosynthesis:

A chromatographic separation of the leaf pigments shows four types of pigments in leaves. They are

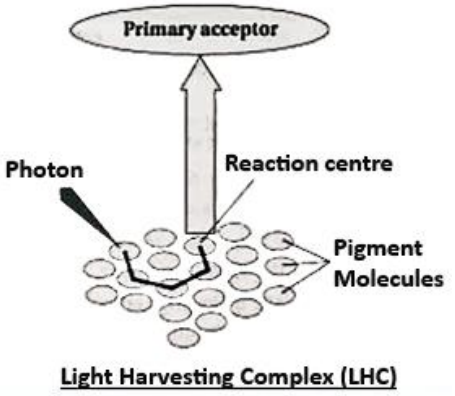
1) Chlorophyll-a Bright or blue green in chromatogram
2) Chlorophyll-b Yellow green
3) Xanthophyll Yellow
4) Carotenoids Yellow to yellow orange

Chlorophyll-a is the chief pigment associated with photosynthesis.

Light Reaction:

Light reactions or the photochemical phase include light absorption, water splitting oxygen release and the formation of high chemical intermediate, ATP and NADPH.

- The pigments are organized into two discrete photochemical light harvesting complexes (LHC) within the photosystem I (PS I) and photosystem II (PS II)
- The LHC are made up of hundreds of pigments molecules bound to a protein.
- Each photosystem has all the pigments (except one molecule of chlorophyll a) forming a light harvesting system also called antennae.
- The single chlorophyll-a molecules forms the reaction centre.



Light Harvesting Complex (LHC)

- The PS I, the reaction centre chlorophyll-a has absorption peak at 700 nm, hence is called P_{700} while in PS II it has absorption maxima at 680 nm and is called P_{680}

The Electron Transport:

- The electron transport system is a series of molecules that accept or donate electrons and move them step by step in a specific direction across a membrane.

- These molecules starting from photosystem II, the reaction centre chlorophyll a absorbs 680 nm wavelength of red light causing e^- to become excited and jump which are picked up by an primary electron acceptor of PS II (Pheophytin) which passes them to an electron transport system consisting of plastoquinone (PQ), cytochrome $b_6 - f$ complex, Plastocyanine (PC), A_0, a special chlorophyll a molecule, primary electron acceptor of PS I, A_1 (phylloquinone), Iron-Sulphur (Fe-S) centres and Ferredoxin
- The electrons then are moved downhill to a molecule of energy rich $NADP^+$ (Hill's reagent) and the addition of these electrons reduces $NADP^+$ to $NADPH + H^+$
- The whole scheme of transfer of e^- is called the z-scheme.

Splitting of Water:

- Splitting of water creates O_2, one of the net products of photosynthesis.

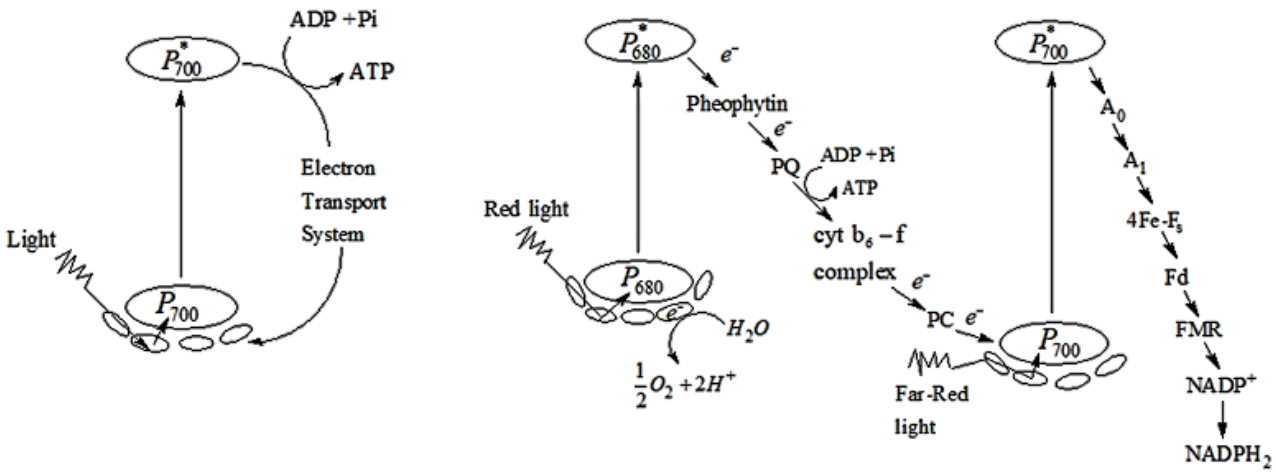
$$2H_2O \rightarrow 4H^+ + O_2 + 4e^-$$

- The splitting of water is carried out by the water splitting complex (also called oxygen-evolving complex) located on the inner side of the membrane of thylakoid in PS II. This complex has a cluster of Mn, Ca and Cl ions

Cyclic and Non-Cyclic Photo-Phosphorylation:

This process in which ATP is synthesized by chloroplasts in the process of light is called photophosphorylation.

	Cyclic Photophosphorylation	Non-Cyclic Photophosphorylation
1)	It involves PS I	It involves both PS I and PS II
2)	It is not connected with photolysis of water, so no O_2 is evolved	It is connected with photolysis of H_2O and liberation of O_2
3)	Electrons move in a closed circle. Electrons expelled from P_{700} return to it after passing through different electron acceptors	Electrons do not move in closed circle. Electrons expelled by the reaction centre P_{680} do not return to it. Here water donates electrons to P_{680}
4)	In each flow of electrons, 2 molecules of ATP are synthesized	In each flow of electrons, 1 molecule of ATP is synthesized
5)	NADPH is not produced	NADPH is produced
6)	It is not inhibited by DCMU (3-(3,4-dichlorophenyl)-1, dimethyl urea)	It is inhibited by DCMU



Chemiosmotic Hypothesis:

- It has been put forward by Mitchell (1961) to explain the mechanism of ATP synthesis.
- When electrons are transported through the electron transport system (ETS), the protons accumulate inside the thylakoid lumen. So a proton gradient across thylakoid membrane is established.
- The proton gradient is broken down due to movement of protons through transmembrane channel F_0 and F_1 of ATPase (ATP synthase)
- F_0 provides facilitated diffusion to H^+ or proton and they bring about conformational changes in F_1 particles of ATPase or coupling factor which forms ATP from ADP and inorganic phosphate.
- One molecule of ATP is formed when $2H^+$ ions pass through ATPase.

Bio Synthetic Phase:

- It involves the fixation and reduction of CO_2 resulting in the formation of carbohydrates. Dark reaction is also called as Blackmann Reaction. It occurs in stroma of the chloroplast.
- Dark reaction does not directly depend on the presence of light but is dependent on the products of light reaction i.e. ATP and NADPH, besides CO_2 and H_2O $[CO_2$ reduced to $C_6H_{12}O_6]$

Calvin Cycle / C_3 Cycle :

This was discovered by Melvin Calvin (1951)

A. Carboxylation:

It is the step in which CO_2 is utilized for the carboxylation of RUBP (Ribulose 1,5 bi phosphate). RUBP is an acceptor molecule of CO_2, a 5-carbon ketose sugar.

- Carboxylation is catalysed by RUBP carboxylase oxygenase (RuBisCo), which results in the formation of 3 PGA (3 phosphoglyceric acid)

B. Reduction:

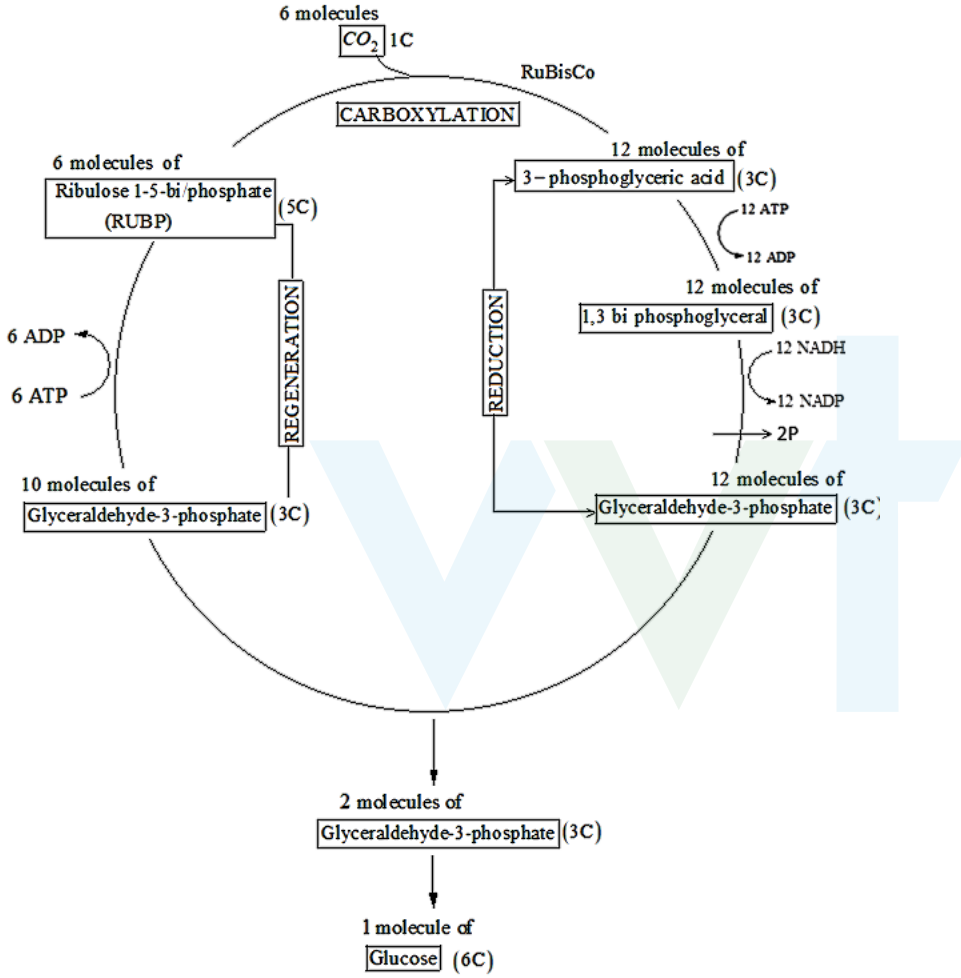
Involves two molecules of ATP for phosphorylation and two NADPH for reduction per CO_2 molecule

fixed. The fixation of six molecules of CO_2 and 6 turns of the cycle are required for the removal of one molecule of glucose from the pathway.

C. Regeneration:

To regeneration of CO_2 acceptor molecule RUBP require one ATP for phosphorylation to form RUBP.

- For every CO_2 molecule entering the Calvin cycle, 3 molecules of ATP and 2 of NADPH are required.
- To make one molecule of glucose, 6 turns of the cycle are required.



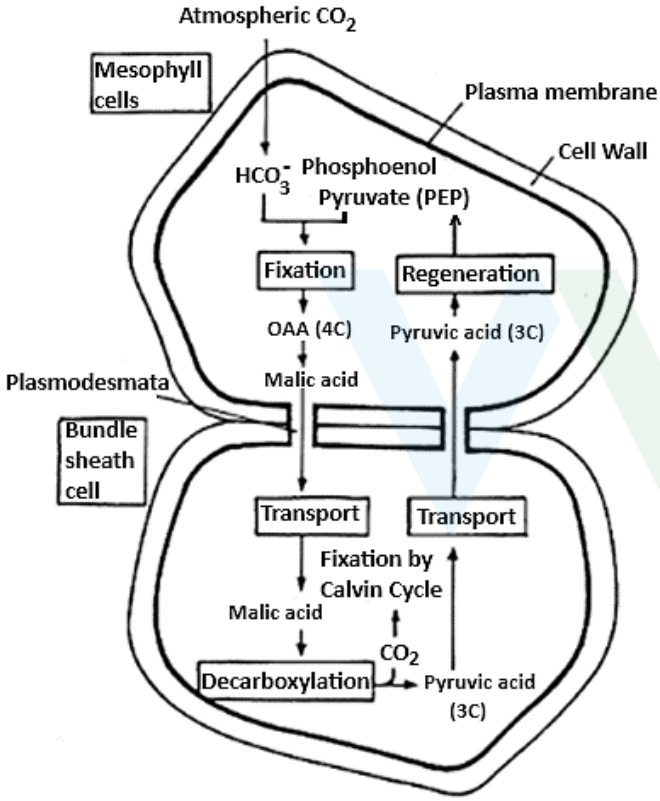
In	Out
6 CO_2	One glucose
18 ATP	18 ADP
12 NADPH	12 NADP

⇒ C_4 -Cycle (Hatch and Slack Pathway) / Dicarboxylic Acid Cycle:

- -- first observed that 4C compound OAA (Oxaloacetic acid) formed during dark reaction in sugarcane.
- Hatch and Slack (1969) studied in detail and proposed a pathway for dark reaction in sugarcane and maize leaves.
- C_4 plants are special because they have a special type of leaf anatomy, particularly large cells around the

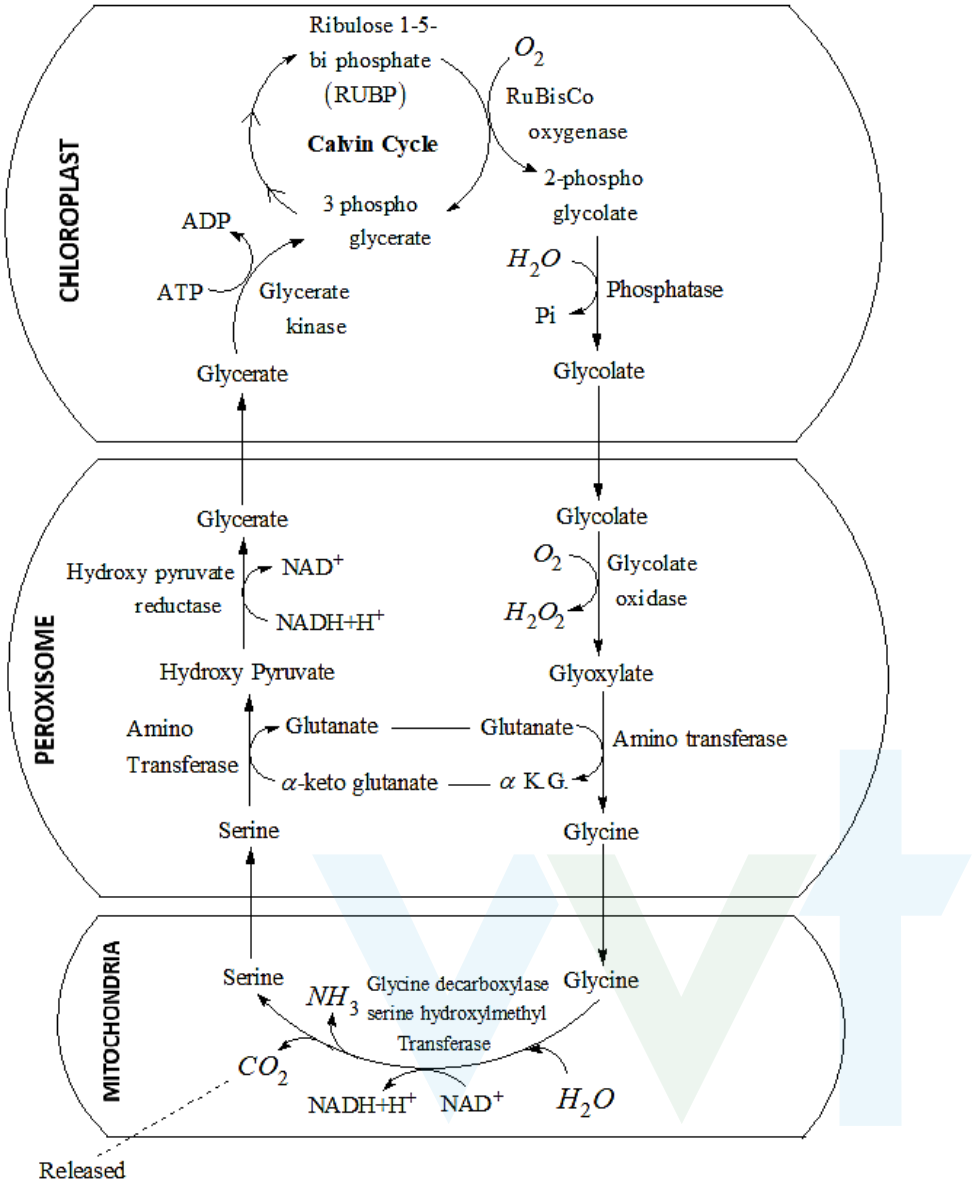
vascular bundles of the C_4 pathway are called bundle sheath cells and the leaves which have such anatomy are said to have Kranz Anatomy, they tolerate higher temperatures, they show a response in high light intensities, they lack a process called photorespiration.

- Bundle sheath cells are characterized by leaving a large number of chloroplasts, thick walls – in gaseous exchange and no intracellular spaces.
- The mesophyll cells lack RuBisCo enzyme and the OAA is formed in the mesophyll cells.
- In bundle sheath cells, these C_4 acids are broken down to release CO_2 and a 3-carbon molecule.
- The 3-carbon molecule is transported back to the mesophyll where it is converted to PEP again.
- The CO_2 released in the bundle sheath cells enters the Calvin pathway.



⇒**<u>Photorespiration:</u>**

- Decker and Tio discovered photorespiration and clarified that C_2 cycle or glycolate pathway operates during day time in C_3 plants and RuBisCo acts an oxygenase at higher concentration of O_2 and low concentrations of CO_2
- Photorespiration is not synthesized sugars, NADPH and ATP as ordinary dark reaction, thus it is harmful or wasteful process linked with C_3 cycle.
- In C_4 plants, photorespiration does not occur because they have a mechanism that increases the concentration of CO_2 at the enzyme site.



⇒Factors affecting photosynthesis:

- Photosynthesis is under the influence of several internal factors like cells and chloroplasts, internal CO_2 concentration, amount of the chlorophyll, include the number, size, age and orientation of leaves, mesophyll.
- Blackman's law of limiting factors states that "If a chemical process is affected by more than one factor, then its rate will be determined by the factor which is nearest to its minimal value." It is the factor which directly affects the process if its quantity is changed.

External Factors:

1. Light: Quality or Wavelength

Maximum photosynthesis takes place in red light than in blue light. But rate of photosynthesis is highest in white light while minimum in green light.

2. Light Intensity:

Rate of photosynthesis is greater in intense light than in diffused light. But at higher light intensity, photooxidation (solarization) occurs and photosynthetic apparatus may get damaged.

3. Temperature:

Optimum temperature is $20-35°C.$ At high temperature rate of photosynthesis decreases due to denaturation of enzymes.

4. Carbon dioxide:

An increase in CO_2 concentration upto 1% (0.03% to 1%) causes rate of photosynthesis to increase.

Higher concentration is toxic to plants and also closes stomata.

- C_4 plants shows saturation at about $360\ \mu l / L$
- C_3 plants shows saturation at only beyond $450\ \mu l / L$

5. Water:

Less availability of water reduces the rate of photosynthesis.

6. O_2 :

High O_2 concentration reduces photosynthesis due to photorespiration (Warburg effect).

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