Photosynthesis and Pigments

Process Overview

Photosynthesis is an enzyme-regulated anabolic process by which green plants manufacture organic compounds inside chlorophyll-conta source. It primarily occurs in the chloroplasts of leaf cells, especially in the mesophyll cells.

Site and Structure

Chloroplasts are green plastids that contain a membranous system of grana (stacks of thylakoids), stroma lamellae, and fluid stroma. The g dark reactions.

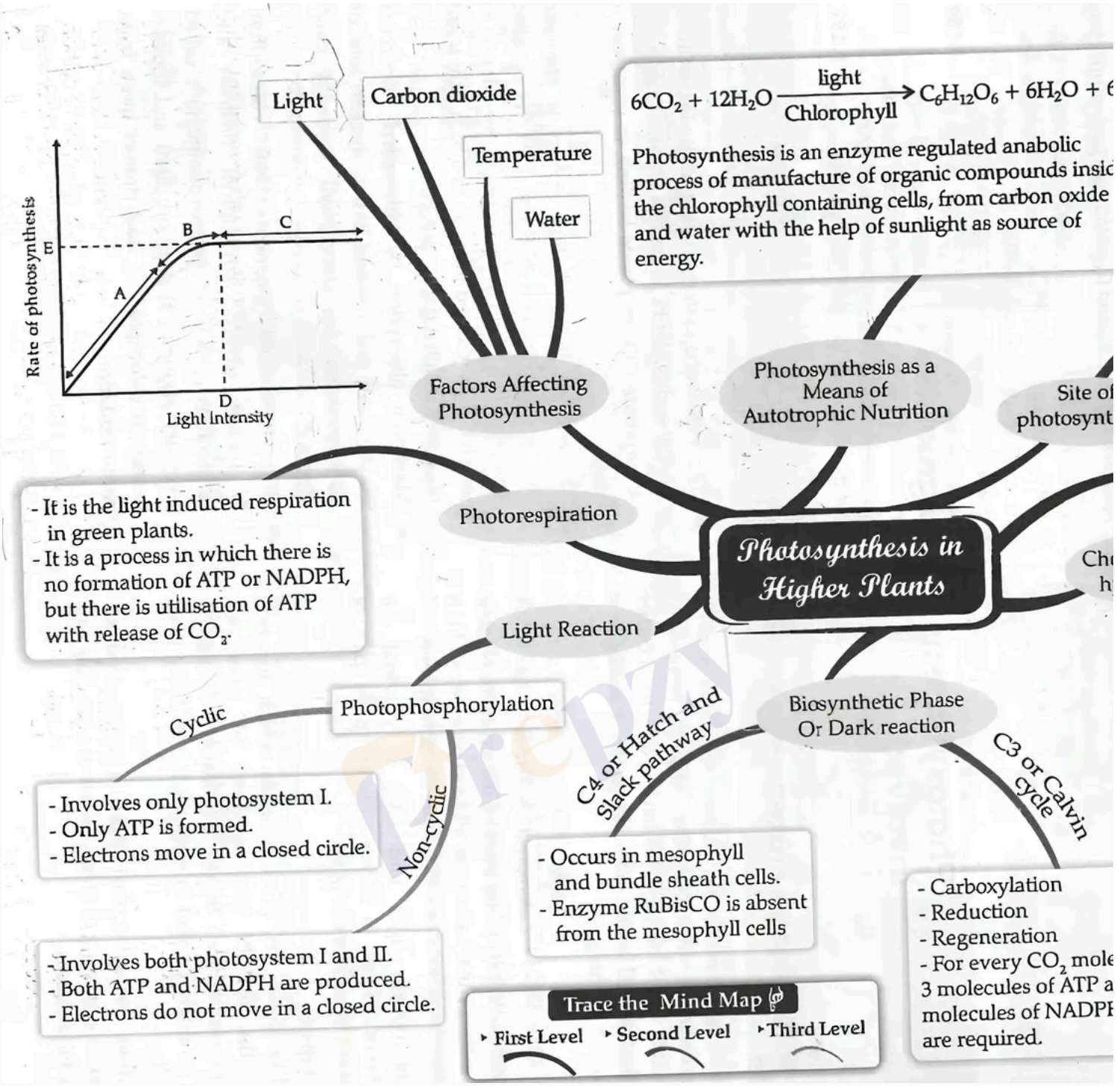
Stages of Photosynthesis

The process consists of two main stages:

- **Light Reaction:** Occurs in the grana where light energy is absorbed by pigments to produce ATP and NADPH, and oxygen is released by
- **Dark Reaction (Calvin Cycle):** Occurs in the stroma where ATP and NADPH are used to fix carbon dioxide into glucose.

Photosynthetic Pigments

Chlorophyll *a* is the chief pigment absorbing mainly blue and red light. Accessory pigments include chlorophyll *b* (yellow-green), xanthophy and transfer energy to chlorophyll *a* and protect it from photo-oxidation.



Solved Examples

Example 1: Write the balanced chemical equation for photosynthesis and explain the role of each reactant and product.

Solution:

The balanced chemical equation is:

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

Explanation:

- Carbon dioxide (CO_2) is taken from the atmosphere and used as a carbon source.
- Water (H_2O) is absorbed from the soil and split during the light reaction to release oxygen.
- Light energy is absorbed by chlorophyll to drive the reactions.
- Glucose ($C_6H_{12}O_6$) is synthesized as food.
- Oxygen (O_2) is released as a byproduct.

Practice Set

- **Level 1 (Easy):** What is the main pigment involved in photosynthesis and what colors of light does it absorb most effectively?
- **Level 2 (Moderate):** Explain the role of accessory pigments in photosynthesis.
- **Level 3 (Challenging):** Describe the structure of chloroplast and explain how it supports the process of photosynthesis.

Answer Key

- **Level 1:** Chlorophyll *a* is the main pigment; it absorbs blue and red light most effectively.
- **Level 2:** Accessory pigments like chlorophyll *b*, xanthophyll, and carotenoids absorb additional wavelengths of light and transfer the ene
- **Level 3:** Chloroplasts have grana (thylakoid stacks) where light reactions occur, and stroma where dark reactions occur. This compartm and carbon fixation.

Photosynthetic Pathways and Factors

Light Reaction Details

The light reaction involves:

- Light absorption by pigments organized in light harvesting complexes (LHC) within Photosystem I (PSI) and Photosystem II (PSII).
- Water splitting (photolysis) releasing oxygen, protons, and electrons.
- Electron transport through cytochromes generating ATP and NADPH.
- Photophosphorylation, the synthesis of ATP using light energy.

Electron Transport and Photophosphorylation

Electrons excited in PSII (P680) move through an electron transport chain to PSI (P700), releasing energy used to form ATP and NADPH. This is

Photophosphorylation occurs in two forms:

- **Non-cyclic:** Electrons flow from water to $NADP^+$, producing ATP, NADPH, and oxygen.
- **Cyclic:** Electrons cycle back to PSI, producing ATP only.

Chemiosmotic Hypothesis

ATP synthesis is driven by a proton gradient across the thylakoid membrane. Protons accumulate inside the thylakoid lumen during electron powering ATP formation.

Calvin Cycle (C_3 Pathway)

The Calvin cycle fixes CO_2 into organic molecules in three steps:

- **Carboxylation:** CO_2 is fixed to ribulose bisphosphate (RuBP) by RuBisCO, forming 3-phosphoglyceric acid (3-PGA).
- **Reduction:** ATP and NADPH reduce 3-PGA to glyceraldehyde-3-phosphate (G3P), a sugar precursor.
- **Regeneration:** ATP regenerates RuBP to continue the cycle.

Six turns of the cycle produce one glucose molecule.

In	
Six CO_2	Or
18 ATP	18
12 NADPH	12

C_4 Pathway

In C_4 plants like maize and sugarcane, CO_2 is first fixed into a 4-carbon compound (oxaloacetic acid) in mesophyll cells by PEP carboxylase. released for the Calvin cycle. This adaptation reduces photorespiration and is efficient in hot, dry climates.

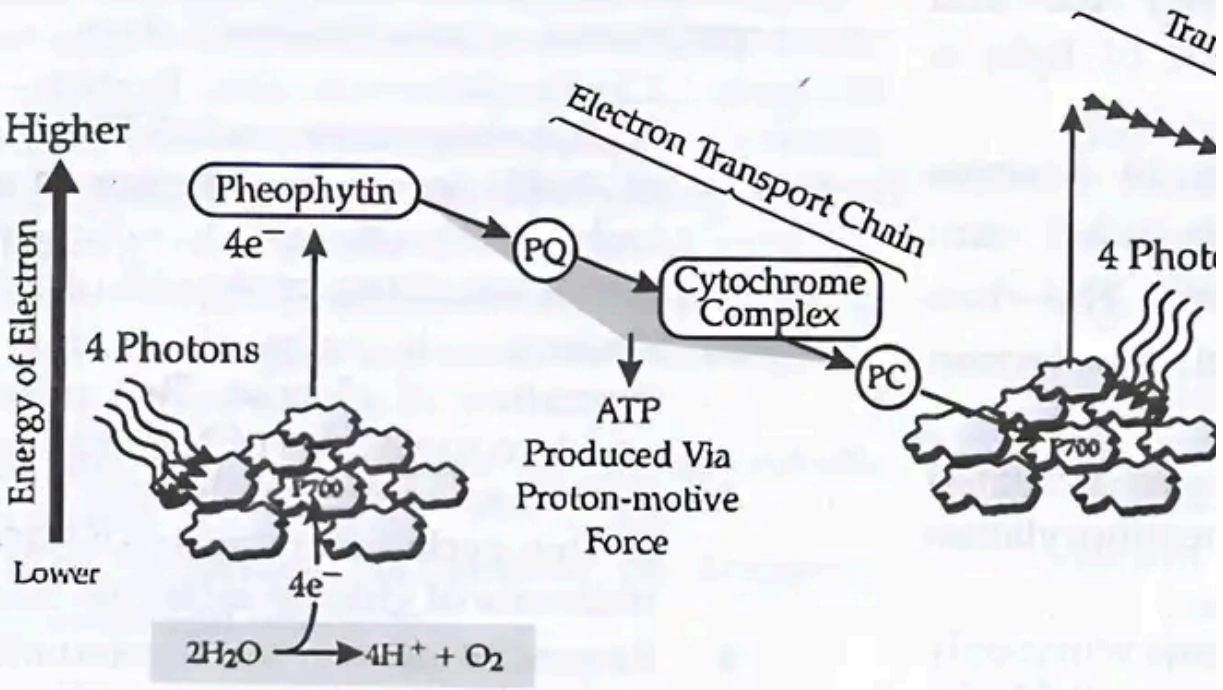
Photorespiration

Photorespiration occurs when RuBisCO binds oxygen instead of CO_2, producing phosphoglycolate and releasing CO_2 without producing ATP plants under high oxygen and light conditions.

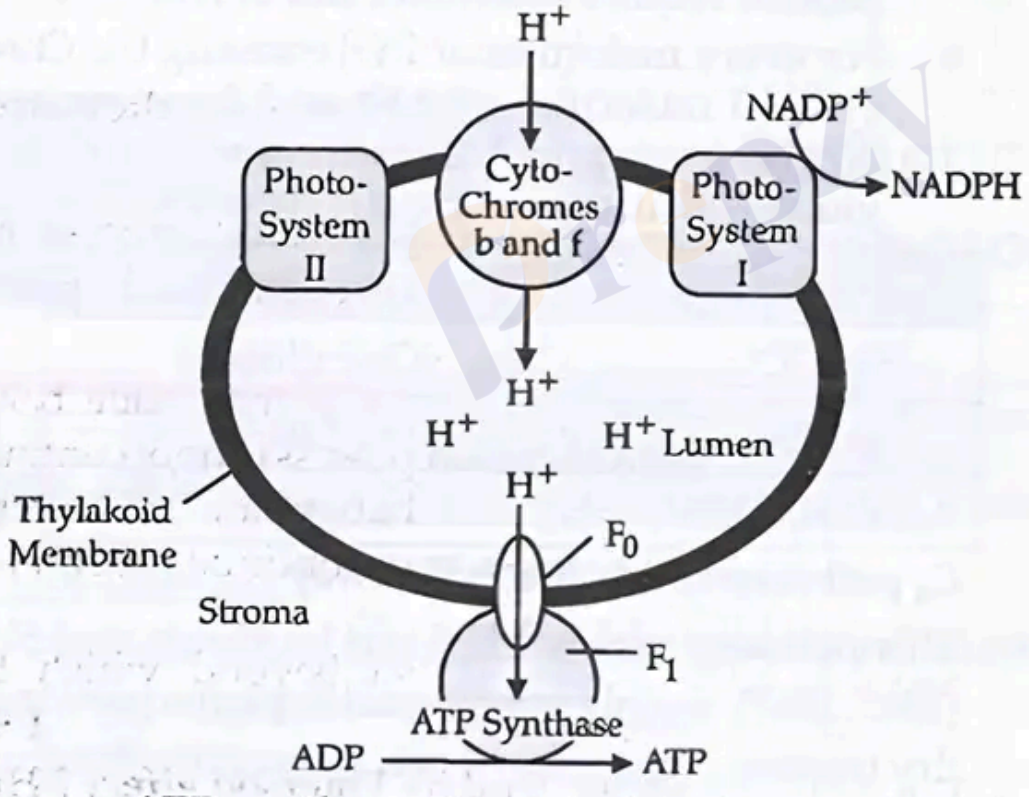
Factors Affecting Photosynthesis

- **Light intensity:** Rate increases with light until saturation.
- **Carbon dioxide concentration:** Rate increases with CO_2 until compensation point.
- **Temperature:** Affects enzyme activity; high temperatures can denature enzymes.
- **Water availability:** Essential but rate plateaus after saturation.

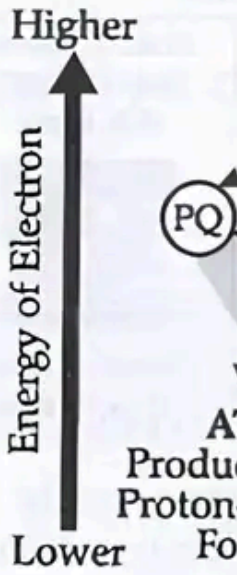
The law of limiting factors states that the rate of photosynthesis is limited by the factor in shortest supply.

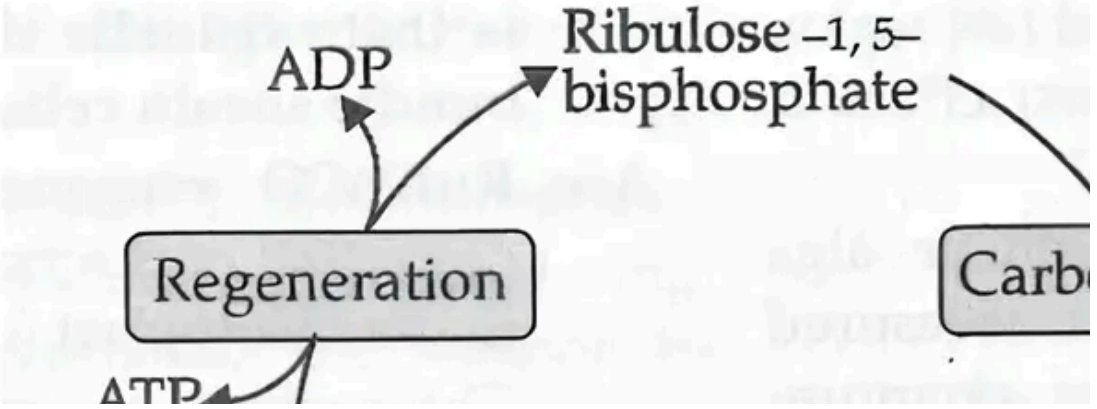


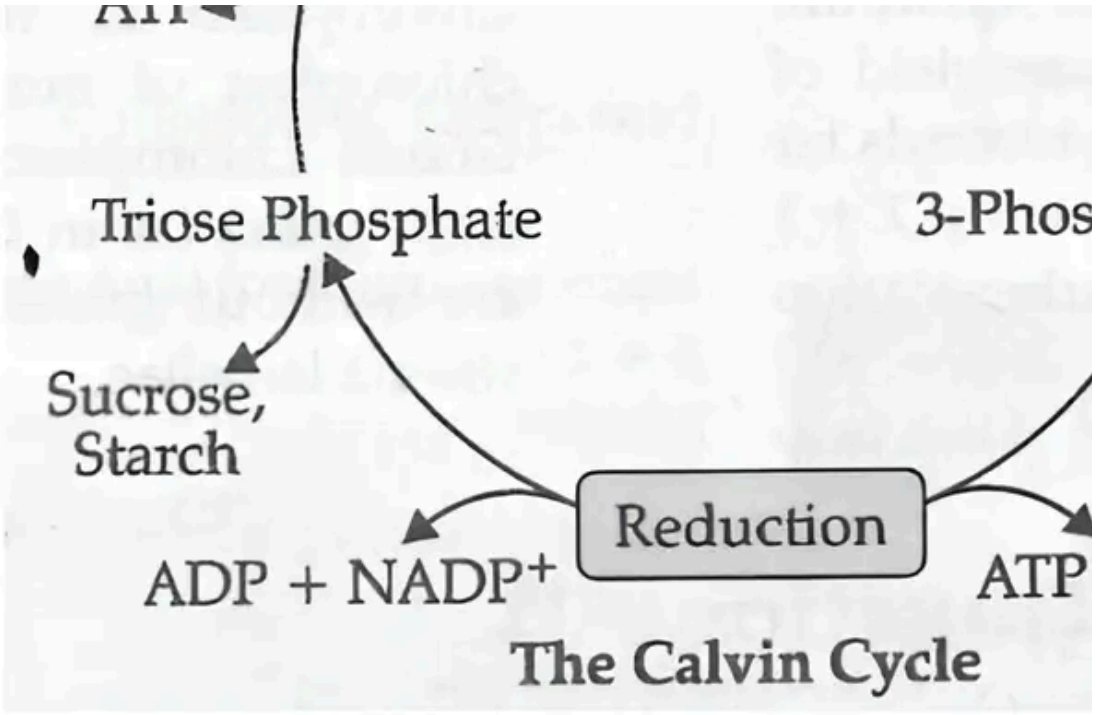
Non-cyclic photophosphorylatio



ATP synthesis through chemiosmosis







Solved Examples

Example 1: Explain the difference between cyclic and non-cyclic photophosphorylation.

Solution:

Cyclic photophosphorylation involves only Photosystem I where electrons cycle back to the electron transport chain, producing ATP but no N

Non-cyclic photophosphorylation involves both Photosystem II and I, producing ATP, NADPH, and oxygen by splitting water.

Example 2: Describe the role of ATP and NADPH in the Calvin cycle.

Solution:

ATP provides energy, and NADPH provides reducing power (electrons) to convert 3-phosphoglyceric acid into glyceraldehyde-3-phosphate,

Practice Set

- **Level 1 (Easy):** What is photolysis and what are its products?
- **Level 2 (Moderate):** Explain the chemiosmotic hypothesis of ATP formation in photosynthesis.
- **Level 3 (Challenging):** Compare the C_3 and C_4 pathways of photosynthesis highlighting their adaptations.

Answer Key

- **Level 1:** Photolysis is the splitting of water molecules during the light reaction, producing oxygen, protons (H^+), and electrons.
- **Level 2:** The chemiosmotic hypothesis states that ATP synthesis is driven by a proton gradient across the thylakoid membrane. Protons
  synthase, powering ATP formation.

- **Level 3:** C_3 pathway fixes CO_2 directly via RuBisCO in mesophyll cells; it is common in temperate plants. C_4 pathway first fixes CO_2 into a sheath cells for the Calvin cycle; it is adapted to hot, dry environments and reduces photorespiration.

Quick Reference Table

Photosynthesis Key Points:

- Site: Chloroplast (grana and stroma)
- Main Pigment: Chlorophyll *a*
- Light Reaction: Produces ATP, NADPH, and O_2
- Dark Reaction (Calvin Cycle): Fixes CO_2 into glucose
- Photolysis: $2H_2O \rightarrow 4H^+ + O_2 + 4e^-$
- Photophosphorylation: ATP synthesis using light energy
- Photorespiration: RuBisCO oxygenation reaction reducing photosynthesis efficiency
- C_3 Pathway: Calvin cycle, first product 3-PGA
- C_4 Pathway: First product oxaloacetic acid, reduces photorespiration

Common Mistakes and Misconceptions

- Confusing light and dark reactions: Dark reaction does not require light but depends on products of light reaction.
- Assuming all chlorophyll pigments absorb the same wavelengths equally.
- Believing photorespiration produces energy; it actually consumes energy and reduces photosynthesis efficiency.
- Thinking oxygen is a reactant; it is a byproduct of photolysis.
- Mixing up cyclic and non-cyclic photophosphorylation roles and products.

Glossary

- **Photosynthesis:** Process by which green plants synthesize organic compounds using light energy.
- **Chloroplast:** Organelle where photosynthesis occurs.
- **Chlorophyll:** Green pigment that absorbs light energy.
- **Photolysis:** Splitting of water molecules during light reaction.
- **Photophosphorylation:** Formation of ATP using light energy.
- **Calvin Cycle:** Series of reactions fixing CO_2 into glucose.
- **Photorespiration:** Oxygenation of RuBP leading to CO_2 release without energy production.
- **C_3 Plants:** Plants using Calvin cycle as main photosynthetic pathway.
- **C_4 Plants:** Plants with an additional CO_2 fixation step reducing photorespiration.