NEET Revision Notes
Biology
Photosynthesis in Higher Plants

Introduction:

- Plants are the primary source of food for all animals on Earth, including humans.
- Green plants synthesise the food they require, and all other organisms rely on them to meet their energy requirements. They produce the food through photosynthesis and are thus classified as autotrophs because they prepare their own food.
- Heterotrophs, which include humans, are species that depend on green plants for nutrition.
- All living things on Earth rely on sunlight for energy.
- Photosynthesis is a biological process in which plants use light energy from the sun to fuel the formation of organic molecules like glucose.
- Photosynthesis is vital for two reasons:
    - ➢ It is the prime source of all food on the planet.
    - ➢ Oxygen is emitted into the atmosphere (which is required for aerobic life to exist on this planet).
- Photosynthesis requires three components:
    - ➢ Chlorophyll, which is the green pigment found in leaves
    - ➢ Light
    - ➢ Carbon dioxide.

Early Experiments:

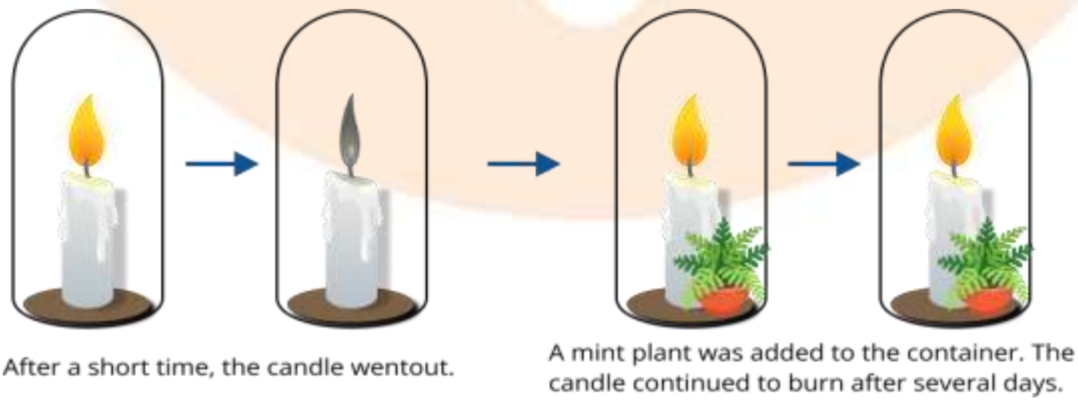

Image: Early experiment of Photosynthesis done by Joseph Priestly

- Joseph Priestly, in 1774, discovered that plants replenish oxygen in the air which respiratory animals and burning candles eliminate.
- Julius von Sachs discovered in 1854 that the green parts of plants are where glucose is produced which is usually saved as starch.
- T.W Engelmann (1843-1909) carried out a fantastic experiment. He used a prism to separate light into its spectrum components before lighting a green alga named *Cladophora* that was dissolved in an anaerobic bacteria solution. The microorganisms were used to discover where O_2 originated. He found that germs gathered primarily in the split spectrum's blue and red light areas. So, the first photosynthesis action spectrum was thus defined, resembling the absorption spectra pigments of chlorophyll a and b.
- The empirical equation then depicted the entire process of photosynthesis for oxygen-evolving organisms: $CO_2 + H_2O \rightarrow [CH_2O] + O_2$

  where CH_2O is a carbohydrate like glucose (6 carbon sugar).
- Cornelius van Neill, a microbiologist, made notable participation in the understanding of photosynthesis by demonstrating that photosynthesis is a light-dependent reaction in which H_2 from an appropriate hydrogen compound, i.e. H_2O, reduces carbon dioxide to carbohydrates.
- The equation can be expressed as,

  $2H_2A + CO_2 \xrightarrow{Light} A + CH_2O + H_2O$
- H_2O is the H_2 donor in green plants and is oxidized to O_2. Some life forms do not produce O_2 during photosynthesis. As a result, it is deduced that O_2 created by plants (green) comes from H_2O rather than CO_2.
- As a result, the photosynthesis equation is as follows:

  $6CO_2 + 12H_2O \xrightarrow{Light} C_6H_{12}O_6 + 6H_2O + 6O_2$
- Photosynthesis occurs in the chloroplasts of mesophyll cells of the green leaves, specifically in the green leaves of plants.

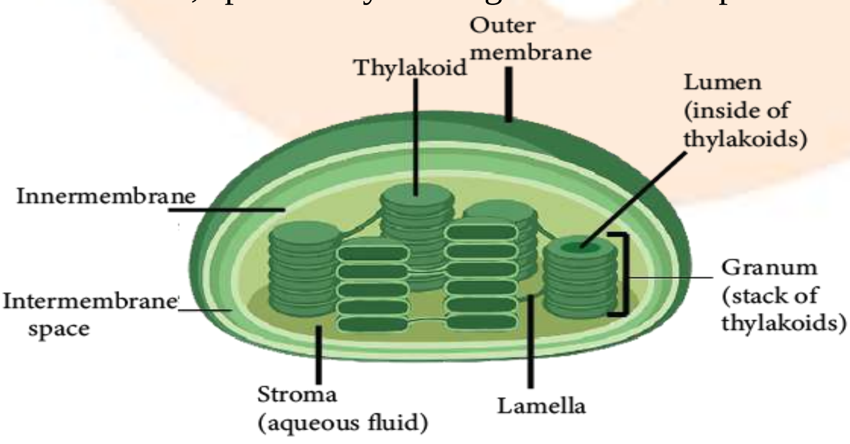

Image: Chloroplast

- The membrane system is responsible for capturing solar energy and producing ATP and NADPH; the reactions or set of reactions participating are light-driven and thus referred to as **Light reactions**.
- Enzymes in the stroma are capable of taking CO_2 and converting it into sugar, which then forms starch; the reactions are not instantly light-driven but are reliant on the components of light reactions, namely ATP and NADPH, and are referred to as **Dark reactions**.

How many different kinds of pigments are required in photosynthesis?

- In leaves, there are four pigments: chlorophyll-a (bluish-green), chlorophyll-b (yellowish-green), Xanthophylls (yellow), and carotenoids (yellow to yellow-orange).

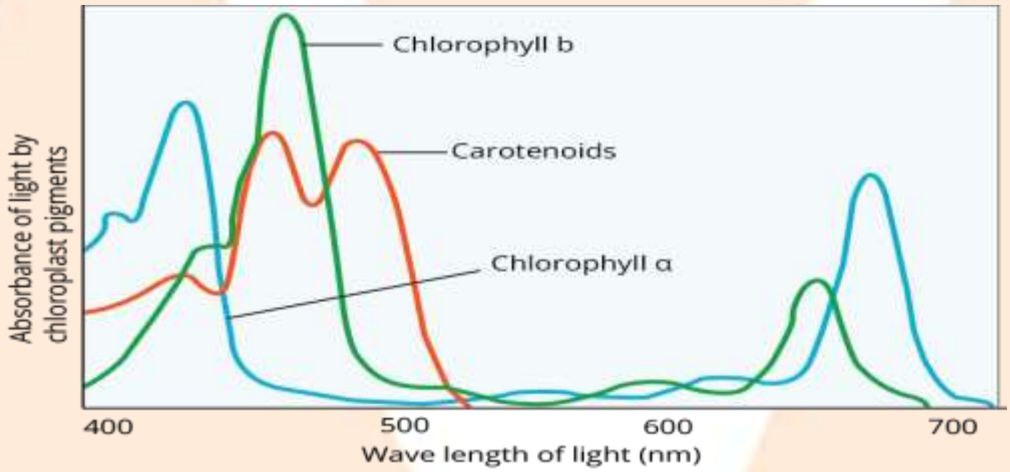

Image: Absorption spectrum of Chlorophyll-a, b, and Carotenoids

- We can reach the conclusion that chlorophyll is the most important pigment involved in photosynthesis.

Light Reaction:

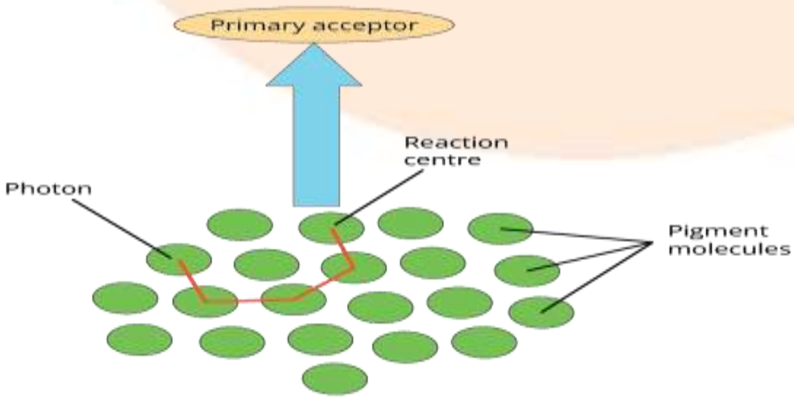

Image: Light-harvesting Complexes

- Absorption of light, splitting of water, releasing oxygen, and creating high-energy chemicals such as ATP and NADPH are all part of the process.
- Several complexes, namely Light-harvesting complexes (LHC) with pigments in Photosystem-1 (PSI) and Photosystem-2 (PSII), are named in the order of their discovery.
- Each photosystem, with the exception of chlorophyll a, contains all of the pigments and constitutes an LHS known as antennae.
- The reaction centre is formed by a single molecule of chlorophyll-a.
- PSI has a maximum absorption at 700 nm, thus is also known as P700 whereas PSII has a maximum absorption at 680 nm, which is known as P680.

Electron Transport System:

- LHC of PSII receives light at 680 nanometers, which excites electrons, causing them to jump out of their orbit and be received by an electron acceptor, which then moves them to the electron transport system.
- Electrons are not used up and are transferred to PSI pigments. Because of the absorption of light at 700 nanometers, these electrons pass to an energy molecule $NADP^+$, leading to the formation of NADPH and H^+.
- The Z scheme is the name given to this electron transport system.

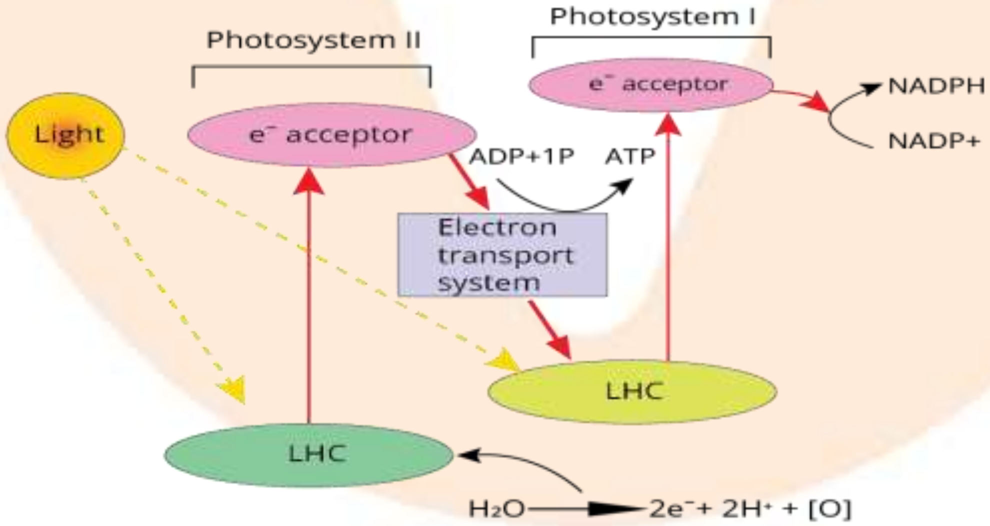

Image: The Z-scheme of electron transport system

Splitting of a water molecule:

- The splitting of H_2O replaces the electrons which were transferred from Photosystem-2. This produces oxygen, a byproduct of photosynthesis.
$2 H_2O \longrightarrow 4 H^+ + O_2 + 4 e^-$
- PSII is associated with this splitting of H_2O. It provides the electrons required to replace those eliminated from PSI.

Cyclic and Non-cyclic Photophosphorylation:

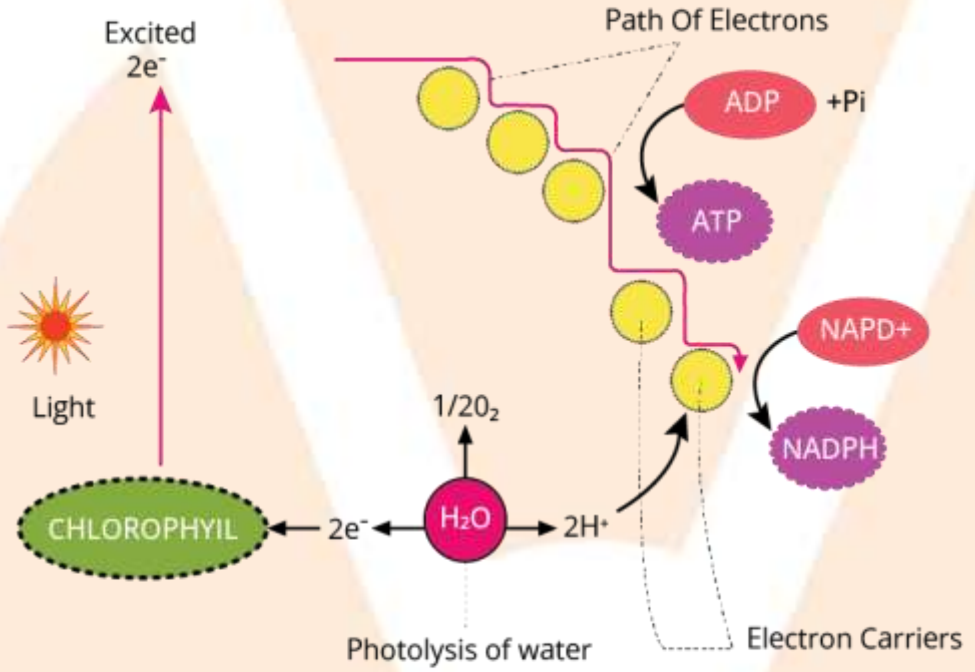

Image: Cyclic Phosphorylation

- Photophosphorylation is the process by which ATP is synthesised from ADP and Pi in the existence of light.
- Non-cyclic photophosphorylation occurs when PSII and then PSI act in series, resulting in the synthesis of both ATP and NADPH.
- Cyclic photophosphorylation occurs when only PSI is active, the electron is distributed within PSI and phosphorylation occurs as a result of the cyclic flow of electrons. It occurs in the stroma lamellae. It lacks the NADP reductase enzyme, so ATP is synthesised but not NADPH and H^+.
- It also takes place when only light with a wavelength greater than 680 nanometers is available.

Chemiosmosis Hypothesis:

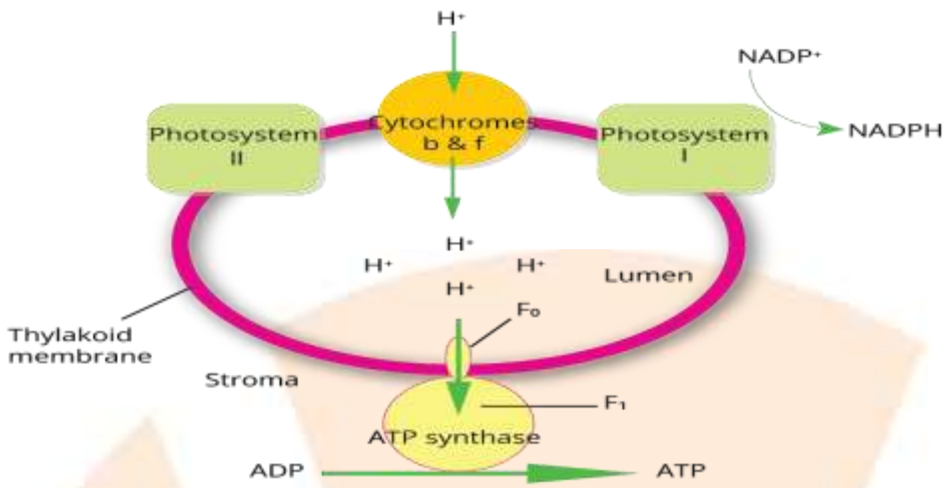

Image: Chemiosmosis Hypothesis

- The ATP synthase enzyme is composed of two parts: F_0 and F_1.
  - ➢ F_0, which is presented into the thylakoid layer and creates a transmembrane channel that enables protons to easily diffuse across the layer.
  - ➢ F_1 is the other half, which is situated on the stroma-facing side of the thylakoid external surface of the membrane.
- The gradient's breakdown offers enough energy to cause a conformational shift in the F_1 moiety of the ATP synthase, allowing the enzyme to synthesise multiple molecules of ATP.
- Chemiosmosis requires a membrane, a proton pump, a proton angle, and ATP synthase.
- To create a gradient or a larger proportion of protons inside the thylakoid lumen, energy is used to pump protons across a membrane.
- ATP synthase contains a channel that allows protons to be released back across the membrane, releasing enough energy to activate the ATP synthase chemical, which catalyses the formation of ATP.
- Along with the NADPH produced by electron development.

Where do ATP and NADPH play a role in photosynthesis?

- These are used in a dark reaction known as the biosynthetic phase of photosynthesis, where food is synthesised.
- There are two pathways for the Dark reaction:
  1. C_3 pathway or Calvin cycle
  2. C_4 pathway or Hatch-Slack pathway

- In the C_3 pathway, the first stable product of the carbon fixation is a three-carbon molecule like PGA (Phosphoglyceric acid) whereas, in the C_4 pathway, it is a four-carbon molecule like OAA (Oxaloacetate).

C_3 pathway or Calvin cycle:

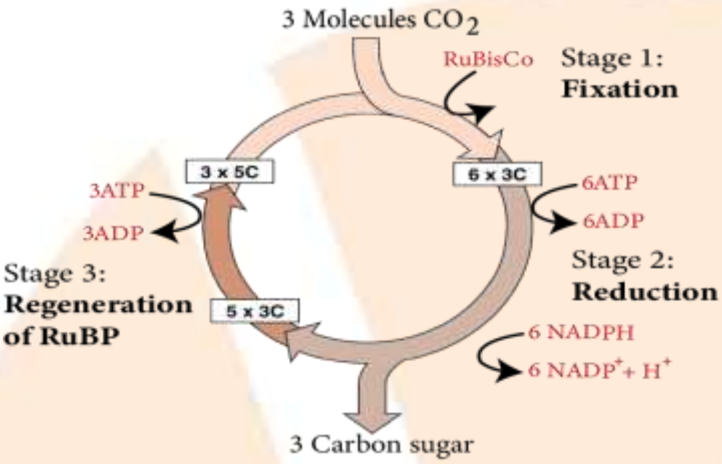

Image: Calvin cycle

- Melvin Calvin found that the first molecule of carbon dioxide fixation was a three-carbon organic acid named 3-phosphoglyceric acid or PGA, hence the **Calvin cycle**.
- The primary CO_2 acceptor in this pathway or C_3 plants is a 5-C-containing RuBP (ribulose bisphosphate) molecule that integrates with CO_2 to generate sucrose.
- Steps included in the Calvin Cycle
  1. **Carboxylation:** In the availability of an enzyme known as RuBP carboxylase-oxygenase (RuBisCO), carbon dioxide is used for decarboxylation of RuBP, resulting in two molecules of 3-PGA. RuBisCO enzyme has an affinity for both carbon dioxide and oxygen.
  2. **Reduction:** Carbon dioxide reduction requires two molecules of ATP for phosphorylation as well as two molecules of NADPH for reduction. Six carbon dioxide molecules must be fixed, as the cycle repeats six times.
  3. **Regeneration:** To regenerate the carbon dioxide acceptor molecule RuBP, one ATP must be phosphorylated.

C_4 or Hatch-Slack Pathway:

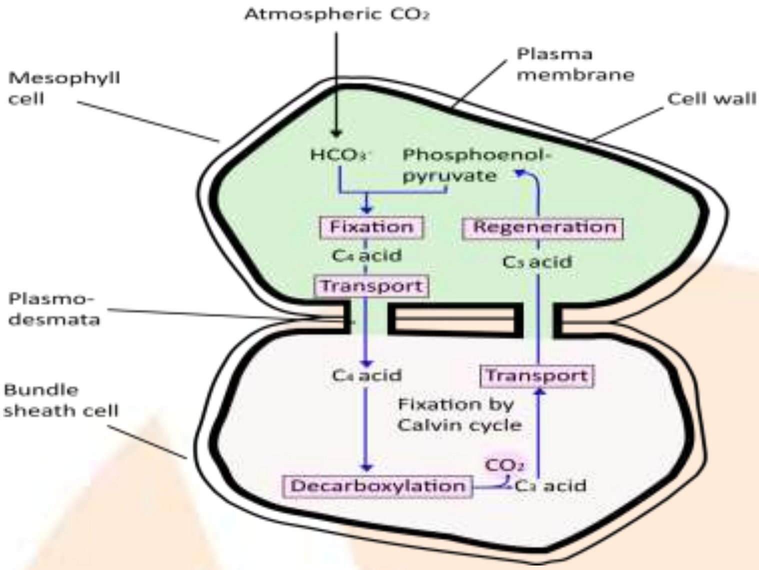

Image: Hatch-Slack Pathway

- The mesophyll cells and vascular bundles are the two types of cells found in the C_4 plants.
- Bundle sheath cells are large cells that surround vascular bundles, and the leaves of these plants have kranz anatomy.
- Bundle sheath cells can have multiple layers of chloroplasts and are resistant to gaseous exchange.
- The mesophyll cells contain the three-carbon molecule called phosphoenolpyruvate (PEP), which serves as the primary carbon dioxide acceptor.
- The enzyme in charge is PEP carboxylase or PEP case, where the RuBisCO enzyme is missing.
- C_4 acid OAA is formed here, which is then transferred to bundle sheath cells where C_4 acids are split to release carbon dioxide and a three-carbon molecule.
- It is then shipped to mesophyll, where it constructs PEP once more, completing the cycle.
- The carbon dioxide produced in the bundle sheath cells reaches the C_3 Calvin pathway, which is shared by all plants, C_3 or C_4.
- The enzyme RuBisCO is abundant in the bundle sheath cells, but PEPcase is lacking. Carbon dioxide gas concentration rises as bundle sheath cells become impermeable to it.

Photorespiration:

- RuBisCO, the most abundant enzyme on the planet, is distinguished by its ability to bind both O_2 and CO_2.
- Some O_2 binds with RuBisCO in C_3 plants, leading to the formation of phosphoglycerate and phosphoglycolate via a pathway known as photorespiration.
- Because there is no production of sugar or ATP/NADPH in this pathway, it is referred to as a wasteful process.
- Photorespiration does not occur in C_4 plants, so they are more productive.

Factors Influencing Photosynthesis:

- The photosynthesis rate is affected by both internal and external factors.
- Internal factors such as the number, size, age, alignment of leaves, chloroplasts, and so on, as well as external factors such as CO_2 concentration, temperature, water, and so on.
- When many factors affect any biological process, Blackman's (1905) Law of Limiting Factors comes into play, which states that if a chemical process is affected by more than one factor, the rate will be determined by the factor that is nearest to its minimal value, which is known as the Limiting factor.
- If the amount is changed, the figure identifies the exact method.

1. Light

- Light is being used as 10% of the incident sunlight.
- It is directly proportional to CO_2 fixation at low intensities. Other factors become confining as the intensity increases.
- Excessive light causes the breakdown of chlorophyll, resulting in a decrease in photosynthesis.

2. Concentration of carbon dioxide

- As carbon dioxide concentrations in the atmosphere are very low, ranging from 0.03 to 0.04 percent, an increase in concentration of up to 0.05 percent can cause an increase in photosynthesis rate.

3. Temperature

- Because the dark reactions are enzymatic, they are temperature controlled. C_4 plants react to higher temperatures and have higher photosynthesis rates, whereas C_3 plants have a lower temperature optimum.

4. **Water**

- Water stress leads to closing of stomata, reducing carbon dioxide accessibility, and causes leaves to wilt, thus reducing the surface area.

Key points to remember:

- Photosynthesis is the process by which green plants produce their own food.
- Carbon dioxide from the environment is obtained by leaves via stomata and used to make carbohydrates, primarily glucose and starch, during this process.
- Photosynthesis occurs only in the green parts of plants, primarily the leaves.
- The mesophyll cells in the leaves contain a large number of chloroplasts, which are capable of CO_2 fixation.
- The light reaction happens within the chloroplasts, while the chemosynthetic process occurs in the stroma.
- The light reaction and the reactions of carbon fixing are the two stages of photosynthesis.
- Light energy is absorbed by the pigments in the antenna and channelled to special chlorophyll molecules known as reaction centre chlorophylls during the light reaction.
- PSI and PSII are the two photosystems. PSI's reaction centre is a 700 nm trapping chlorophyll, a P700 molecule, whereas PSII reaction centre is a P680 that consumes red light at 680 nm.
- After absorbing energy, electrons are emitted and relocated through PSII and PSI to NAD, where they combine to form NADH.
- During this process, a proton gradient is formed across the thylakoid membrane.
- The loss of the protons gradient caused by movement through the portion of the ATPase enzyme emits sufficient energy for ATP synthesis.
- PSII is correlated with water molecule splitting, which leads to the release of O_2, protons, and electron transfer to PSII.
- CO_2 is introduced by the enzyme RuBisCO to a 5-carbon compound RuBP, which is then converted into two molecules of 3-carbon PGA.
- The Calvin cycle then converts this to sugar, and the RuBP is recharged.

- ATP and NADPH produced during the light reaction are used in this process. RuBisCO also catalyses photorespiration, an inefficient oxygenation reaction in C_3 plants.
- Some tropical plants exhibit a type of photosynthesis known as the C_4 pathway.
- The first stable product of CO_2 fixation in the mesophyll in these plants is a 4-carbon compound.
- The Calvin pathway is used in bundle sheath cells to synthesise carbohydrates.