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Photosynthesis in Higher Plants

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Key Takeaway

1. **Photosynthesis**
   - Ingredients
2. **Contribution of scientists**
3. **Plant pigments**
   - Classification
   - Action spectrum
   - Chloroplast
4. **Photosystems**
5. **Mechanism of photosynthesis**
   - Reactions of photosystem I
   - Reactions of photosystem II
6. **Photophosphorylation**

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7 Chemiosmotic theory

8 Dark reaction/ Calvin cycle

9 C_4 plants & pathway

10 Photorespiration/ C_2 cycle

11 Factors affecting photosynthesis

12 Significance of photosynthesis

Summary

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Photosynthesis

Organic compounds synthesised

Reactants	Physical component	Products
Carbon dioxide + Water	Sunlight → Chlorophyll	Glucose + Oxygen
		↓ Organic component

Photosynthesis **is anabolic, endergonic (require energy)** and **oxido-reduction** process.

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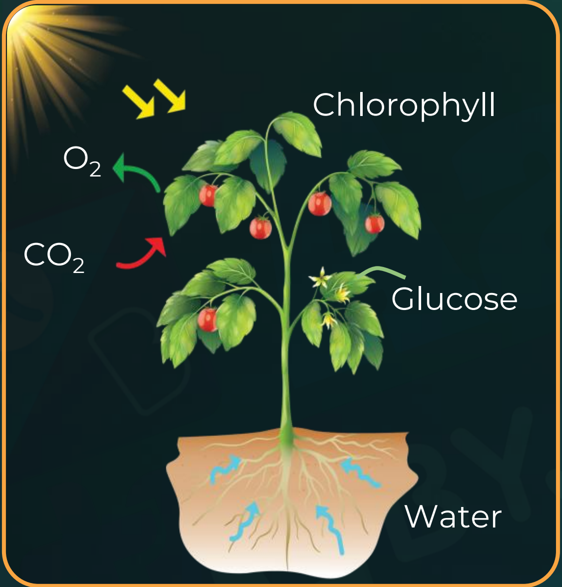
Ingredients of Photosynthesis



Sunlight

Water

Pigments

Carbon dioxide

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Ingredients of Photosynthesis

Carbon dioxide

- During the day, plants take in carbon dioxide and release oxygen during photosynthesis.
  - Experimental proof: Mohl's half leaf experiment

Water

- Water is an **essential ingredient** for **photosynthesis**.
- The **oxygen** evolved from the plants by photosynthesis comes from water.

Sunlight

- Sunlight is an essential aspect of plant growth and plays an important role in photosynthesis.
- **Less/low sunlight = Slow photosynthesis.**

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Ingredients of Photosynthesis

Sunlight

- **Phototropism:** It is a phenomenon in which plants bend towards light.
    - Auxin in plant cells makes them grow longer in shady regions and get exposed to sunlight.
- **Photomorphogenesis:** The development of plants (in terms of shoot length) is also dependent on sunlight.

Pigments

- Pigments are substances that **give colour to leaves**.
- They absorb certain wavelengths of light.
- They play an essential role in photosynthesis.

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Contribution of Scientists

Mohl's half leaf experiment: Showed that CO_2 is required for photosynthesis.

Priestley: Revealed the essential role of air in the growth of green plants through several experiments

Jan Ingenhousz: Showed that sunlight is essential for the plants' process to purify the air

Julius Von Sachs: Found that glucose is made in the green parts of plants

T.W. Engelmann: Described first action spectrum of photosynthesis by using *Cladophora*

Cornelius Van Niel: Demonstrated that photosynthesis is a light-dependent reaction in which hydrogen from a suitable oxidisable compound reduces carbon dioxide to carbohydrates

Ruben, Kamen et. al: Proved that O_2 evolved during light reaction comes from H_2O not from CO_2

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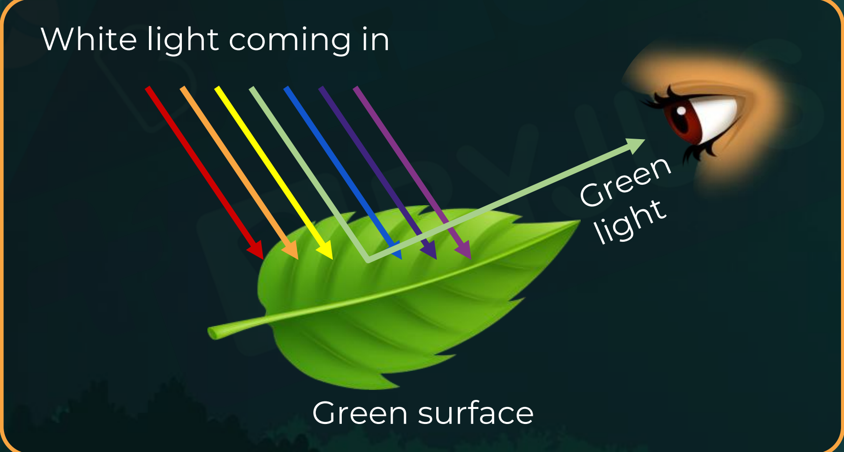
Plant Pigments

- Most leaves appear green as they **reflect green light** and absorb the other wavelengths of light.
- Some leaves are of **different colours** due to the presence of **different pigments** like carotenoids, xanthophylls, etc.
- Amongst the constituents of white light, red and blue wavelengths are the best to carry out photosynthesis.
    - This can be inferred from Engelmann's experiment.



Green surface

Differently coloured leaves

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Classification of Photosynthetic Pigments

- **Photosynthetic pigments**
  - **Chief pigment**
    - **Chlorophyll a**
  - **Accessory pigment**
    - **Chlorophyll b**
    - **Carotenoid**
    - **Xanthophyll**

Major pigment involved in trapping light.

- Absorb light and transfer energy to chlorophyll a
- Allow a wider range of wavelength to be used
- Protect chlorophyll a from photo-oxidation

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Action Spectrum

- It is a graph between the **rate of effectiveness of a biochemical reaction** (Y-axis) plotted against the wavelength of light (X-axis).
- It shows the **effectiveness of different wavelengths of light** with respect to a particular reaction.
- **Engelmann's experiment** is also known as an **action spectrum experiment**.
  - The accumulation of bacteria in the ***Cladophora*** in a particular fashion led to the discovery of action spectra.
- The wavelength of light at which the highest rate of photosynthesis occurs is shown by this spectrum.

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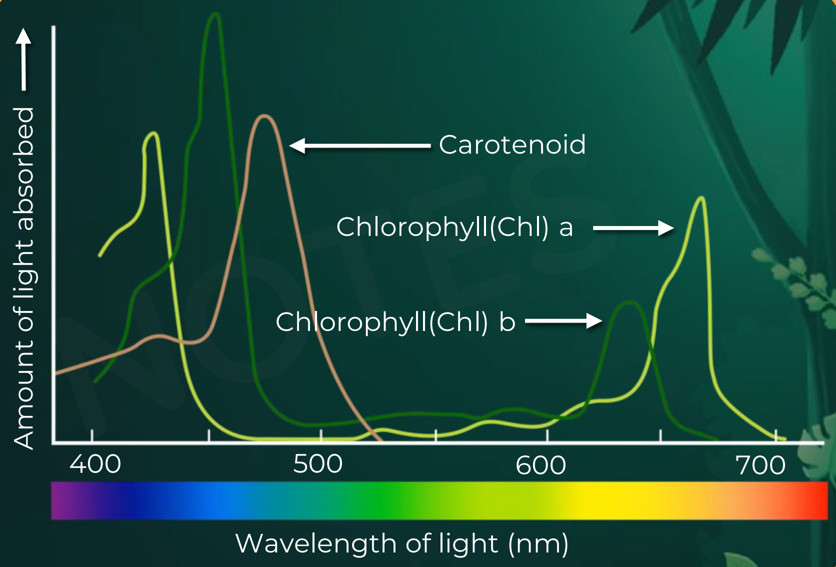
Action Spectrum

- A material's **absorption spectrum is the fraction of radiation absorbed by the material over a range of frequencies**.
- **Chl a and Chl b show absorption in both red** and **blue** regions while carotenoids absorb in the blue-green and the violet region.
- The absorption spectrum indicates the wavelengths of light absorbed by each pigment.
- **Chl b also absorbs considerably very less amount of light** in the red region of the spectrum compared to chl a.
- Therefore, **Chl a is more effective and the chief photopigment**.



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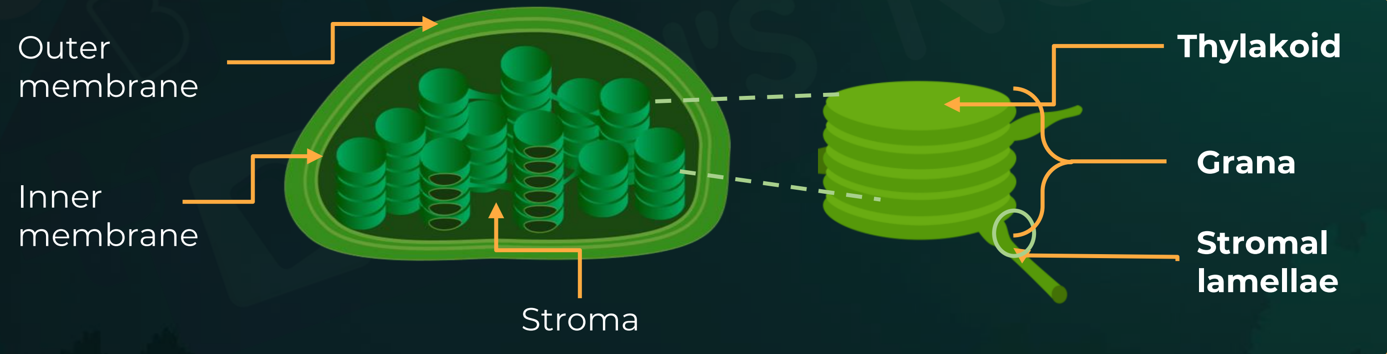
Chloroplast

- Leaves contain **mesophyll cells**. They are a part of ground tissue and house a large number of chloroplasts.
- Chloroplasts contain photosynthetic pigments.
- Mesophyll cells contain many chloroplasts. **(20–100 chloroplasts are present per cell)**.
- Chloroplasts align towards the wall of the cells such that they receive the optimum quantity of sunlight.



Chloroplast structure

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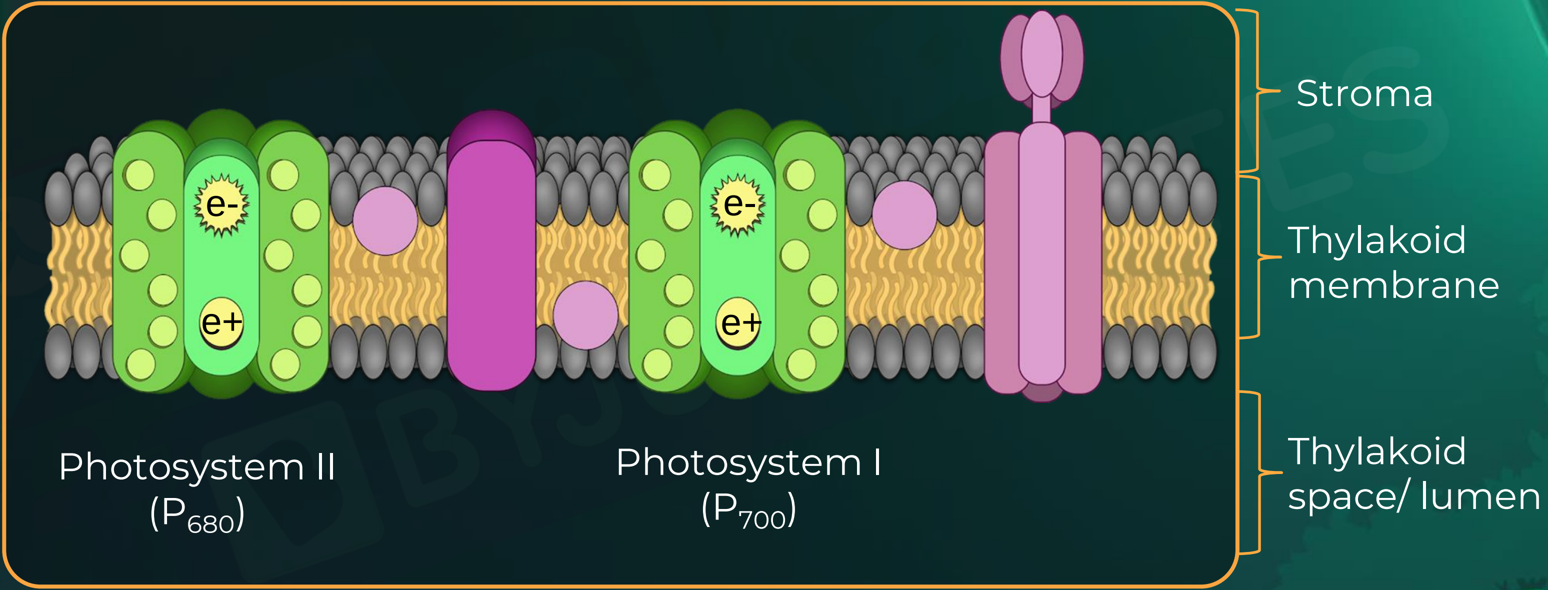
Photosystems

- They are a complex of proteins, photopigments, and organic molecules embedded in the thylakoid membrane of chloroplasts.



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Plant Pigments

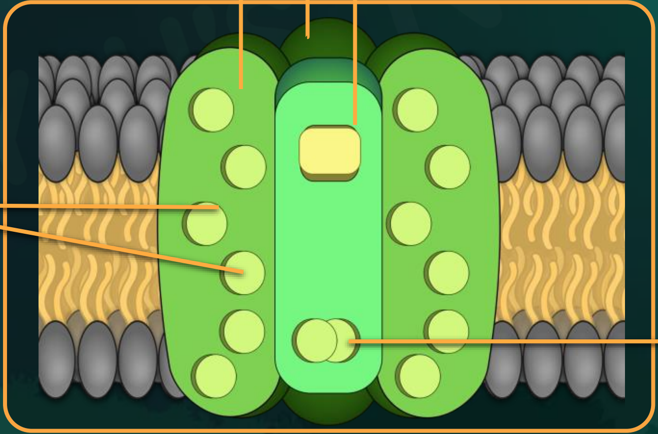
Components of photosystem

Antenna complex/Light harvesting complex

- System of **photopigments and proteins**
- Each **LHC (antenna complex)** is made of hundreds of pigment molecules attached to proteins.
- Possesses **accessory pigments**
- (chlorophyll b, carotenoids, and xanthophylls)

Reaction center

- Possesses chlorophyll a (chief pigment)



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Photosystem I and II

PS I	PS II
Chlorophyll a, present in the reaction centre, has an absorption maxima at 700 nm.	Chlorophyll a, present in the reaction centre, has an absorption maxima at 680 nm.
Known as P_{700} based on the absorption wavelength.	Known as P_{680} based on the absorption wavelength.

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Mechanism of Photosynthesis

Photosynthesis

Light reactions/ Photochemical reactions

1. Sequence of reactions that are directly driven by light
2. Light energy is absorbed by the pigments in the antenna and channelled into chlorophyll a.

Dark reactions

1. Reactions that are independent (or not directly dependent) on light
2. The reactions occur inside the stroma to synthesise sugar molecules. Further, sugar is converted into starch.

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Light Reaction

- Light reaction include
  - Light absorption
  - Water splitting
  - Oxygen release
  - Formation of high-energy chemical intermediates (ATP and NADPH)
- The pigments involved are organised into two discrete photochemical light harvesting complexes (LHC) within
  - **Photosystem I (PS I)**
  - **Photosystem II (PS II)**
- The LHC are made up of hundreds of pigment molecules bound to proteins.
- Each photosystem has all the pigments (except chlorophyll a) contributing to form a light harvesting system also called **antennae**.

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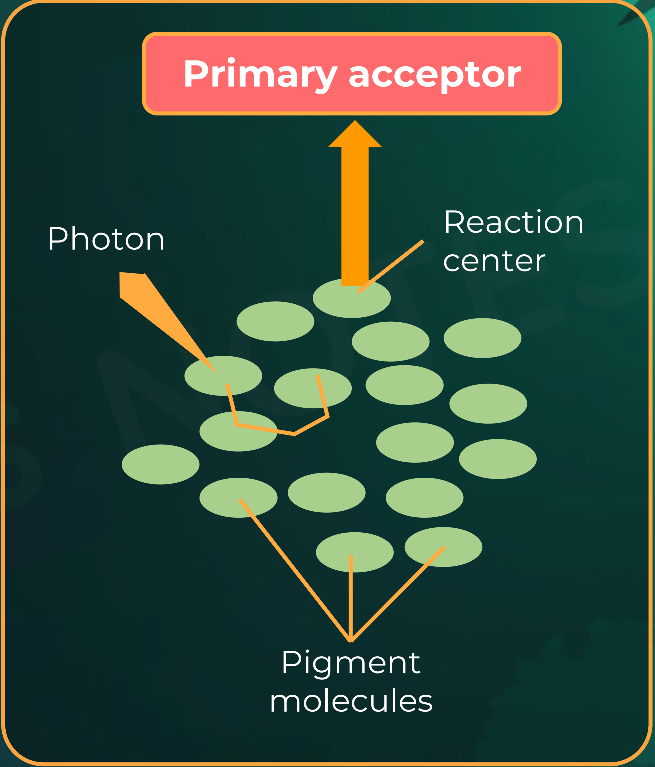
Light Reaction

- These pigments help to make photosynthesis more efficient by absorbing different wavelengths of light.
- The single chlorophyll a molecule forms the reaction centre.
- The reaction centre is different in both the photosystems.
- In **PS I**, the reaction centre **chlorophyll a has an absorption peak at 700 nm**, hence is called P700.
- In **PS II,** it has **absorption maxima at 680 nm**, and is called P680.



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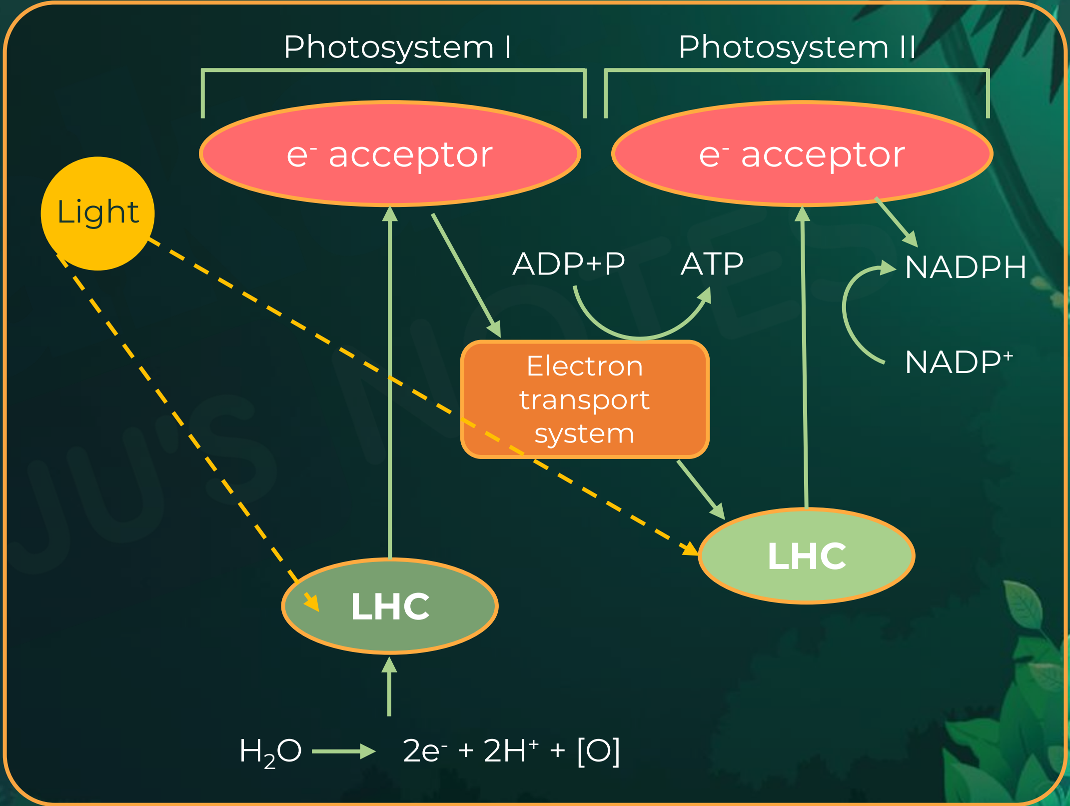
Light Reaction

- In **PS II,** the reaction centre chlorophyll a absorbs 680 nm wavelength of red light.
- This causes electrons to **become excited** and **jump** (uphill) into an orbit farther from the atomic nucleus.
- These electrons are **picked up by an electron acceptor** which passes them to an **electrons transport system** consisting of cytochromes.



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Electron Transport

- **PS II electrons are**
  - Not used up as they pass through the electron transport chain
  - Passed on to the pigments of photosystem PS I
- **PS I electrons are**
  - Also excited when red light of wavelength 700 nm is received
  - Transferred to another acceptor molecule that has a greater redox potential
- These electrons then are moved downhill again, to a molecule of energy-rich $NADP^+$.
- The addition of these electrons reduces $NADP^+$ to $NADPH^+$ H^+.

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Electron Transport

- This whole scheme of transfer of electrons, starting from the PS II, uphill to the acceptor, down the electron transport chain to PS I, excitation of electrons to another acceptor, and finally downhill to $NADP^+$ reducing it to NADPH + H^+ is called the **Z scheme**, due to its characteristic shape.
- This shape is formed when all the carriers are placed in a sequence on a redox potential scale.

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Splitting of Water

Photolysis of water

- **Photolysis** is the **splitting** of **water** in the presence of **sunlight** to yield:
  - Four H^+ ions or protons
  - Four electrons
  - One oxygen molecule
- Thus, this creates oxygen as a net product of photosynthesis.
- Photolysis is **catalysed** by the **PS II** located on the inner side of the **thylakoid membrane**.

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

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Photophosphorylation

Cyclic photophosphorylation	Non-cyclic photophosphorylation
Synthesis of ATP during the light reaction of photosynthesis by cyclic passage of electrons to and from P700. When plants need more ATP than NADPH.	Synthesis of ATP during the light reaction of photosynthesis in which an electron donor is required and oxygen is produced as by product.
Occurs in isolated chloroplasts and photosynthetic bacteria.	Occurs in higher plants, algae and cyanobacteria.
Occurs in anoxygenic photosynthesis (No oxygen evolved).	Occurs in oxygenic photosynthesis (Oxygen evolved).
Final electron acceptor is P_{700}.	Final electron acceptor is NADP+.

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Photophosphorylation

Cyclic photophosphorylation	Non-cyclic photophosphorylation
Electrons move in a cyclic pattern	Electrons in a linear pattern, also known as the Z scheme
Only photosystem I is involved	Both photosystem I and II are involved
Electrons are first expelled from the reaction centre of PS I	Electrons are first expelled from the reaction centre of PS II
Electrons return to the P700 after passing through ETS	Electrons return to the P680(after photolysis of water) and are accepted by NADP+
Photolysis does not occur	Photolysis occurs

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Chemiosmotic Theory

- This theory states that the **synthesis of ATP** which is linked to the development of a **proton gradient** across a membrane (inner side of the thylakoid membrane).
- The **facilitated diffusion** of protons or H^+ ions (due to the proton gradient) **through the ATP synthase** across a membrane leads to the formation of ATP.
- A **high concentration** of **H^+ ions** or **protons** is created in the **thylakoid lumen** due to the following:
  - The influx of H^+ ions during the **electron transport** by **PQ**.
  - Release of H^+ ions due to the **splitting of water** catalysed by **PS II**.
  - Influx of H^+ ion due to **NADP reductase enzyme**.
- A higher H^+ ion concentration at the thylakoid lumen means that there's a **lower H^+ ion concentration** in the **stroma**.

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Chemiosmotic Theory

- **ATP synthase** consists of the following two parts:
  - **CF_0**
    - Embedded in the **thylakoid membrane**.
    - Forms a transmembrane channel that carries out **facilitated diffusion** of **H^+ ions or protons** across the membrane.
  - **CF_1**
    - Protrudes on the **outer surface** of the thylakoid membrane.
    - Faces the **stroma**.

- The breakdown of the gradient provides enough energy to cause a conformational change in the CF_1, which makes the enzyme synthesise packed ATP.

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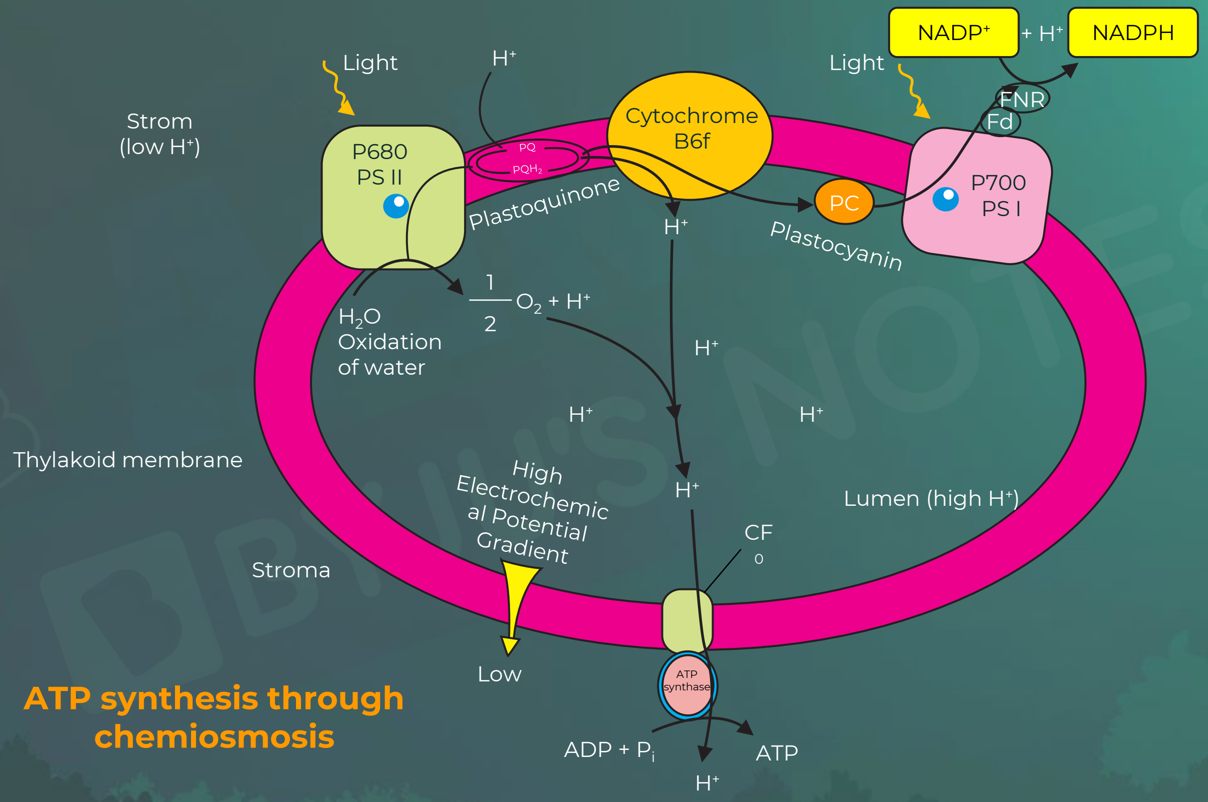
Chemiosmotic Theory



ATP synthesis through chemiosmosis

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Dark Reaction

- Dark reaction does not mean that it occurs only at night even though light is not required for this reaction.
- It takes place in the **stromal matrix** of chloroplast where all the enzymes required for the reaction are present.
- This process does not depend directly on the presence of light but is dependent on the products of light reaction i.e., ATP and NADPH.
- The dark reaction occurs through **Calvin cycle**.

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Calvin Cycle

Calvin cycle

- **Carboxylation**
  CO_2 is fixed
- **Reduction**
  3 PGA is reduced
- **Regeneration**
  RuBP is regenerated

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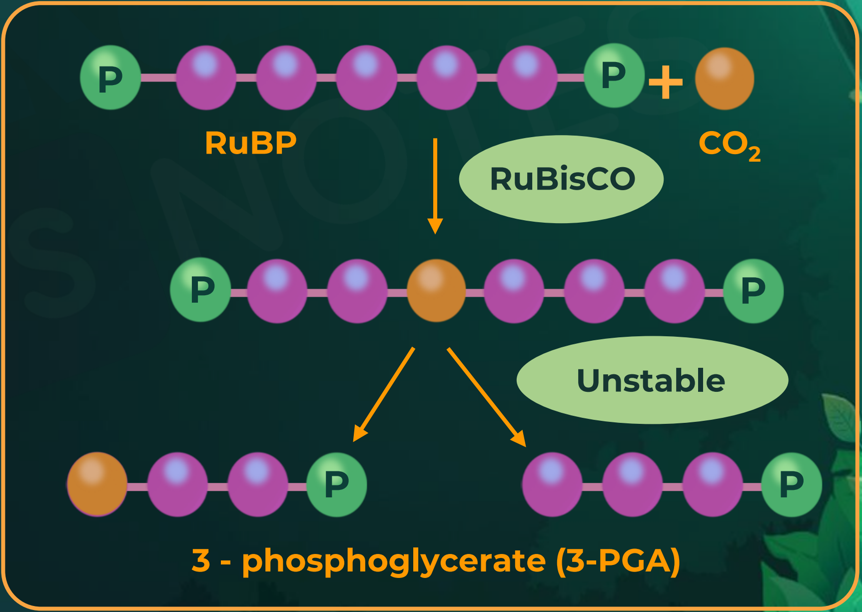
Calvin Cycle

Carboxylation

- During **carboxylation or carbon dioxide fixation**, CO_2 combines with RuBP.
- This fixation forms an **unstable 6 carbon** compound. This reaction is catalysed by the enzyme **RuBisCO**.
- The 6 carbon compound splits into two molecules of **3-PGA** (3-phosphoglycerate or 3-phosphoglyceric acid).
- 3-PGA is a 3-carbon compound and the first stable product formed during the **Calvin/C3 cycle**.

- RuBP + CO_2 ⟶ 2 molecules of **3 PGA**



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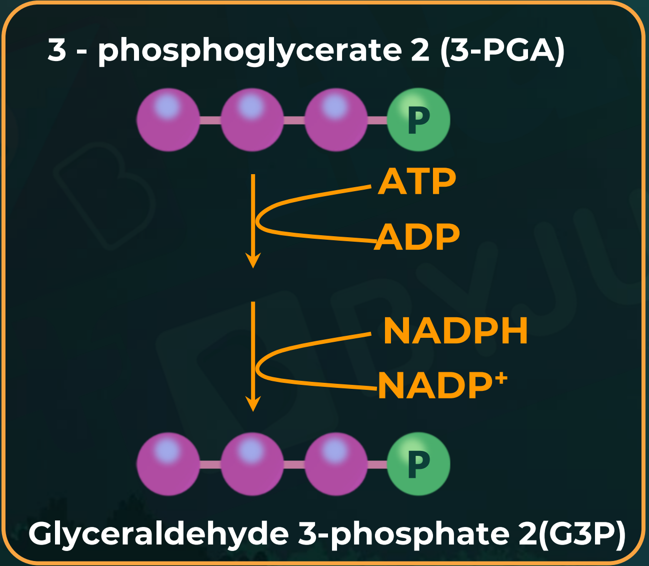
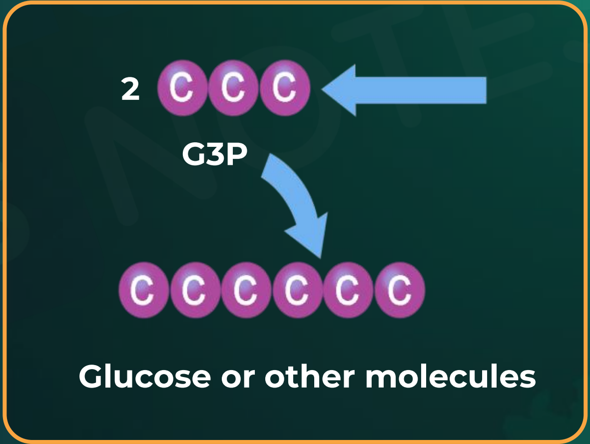
Calvin Cycle

Reduction

- **2** molecules of **3PGA** are converted to 2 molecules of **glyceraldehyde-3-phosphate (G3P).**
- **Two G3P molecules** are easily converted into a **glucose molecule**.





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Calvin Cycle

Regeneration

- RUBP is **ribulose- 1,5-bisphosphate**- a 5-Carbon ketose sugar.
- It is primary **acceptor of CO_2**.
- RuBP accepts CO_2 in the presence of an enzyme known as **RuBisCO**.

- RuBisCO stands for **Ribulose-1,5-bisphosphate carboxylase-oxygenase**
- **Has active site** for both **CO_2** and **O_2**
- Has **greater affinity for CO_2** when CO_2 and O_2 are nearly equal i.e. binding is competitive

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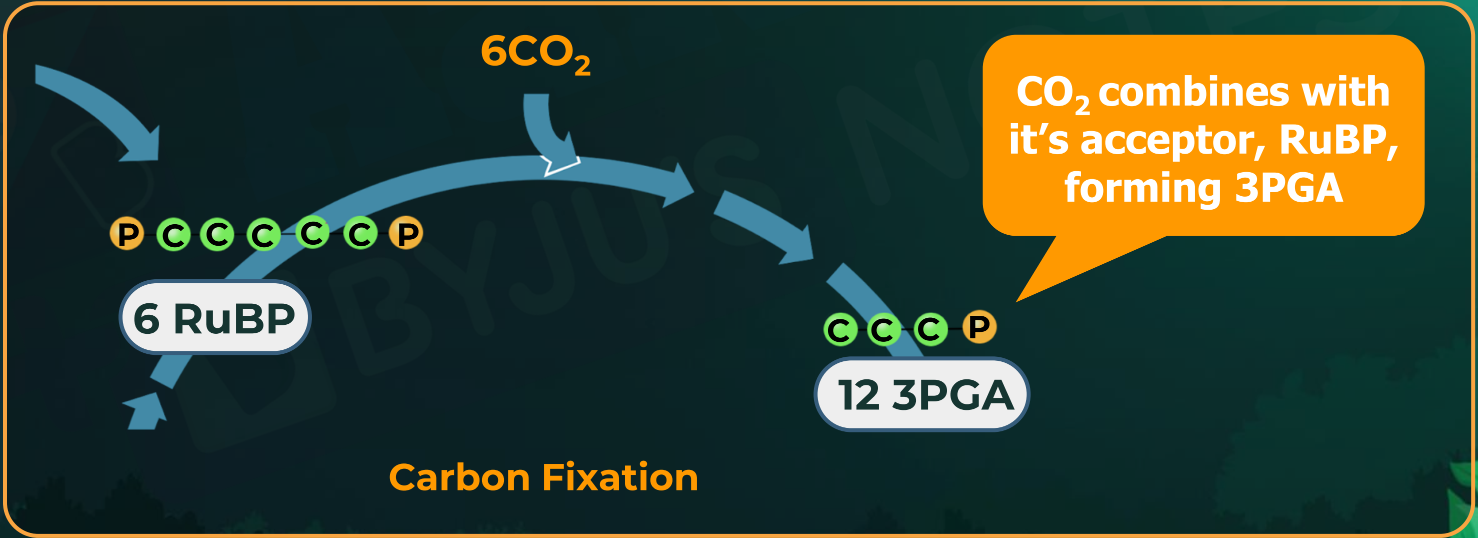
Calvin Cycle

Regeneration I

- **6 CO_2 molecules** are required to make one glucose molecule.
- **6 RuBP + 6 CO2 = 12 3PGA molecules.**



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Calvin Cycle

Regeneration II

- **12 3-PGA** molecules form **12 molecules of G3P**.
- **2 G3P** molecules, out of the 12 G3P - form **a molecule of glucose**.
- **10 of the 12 molecules of G3P** are converted to **6 molecules of RuBP**.

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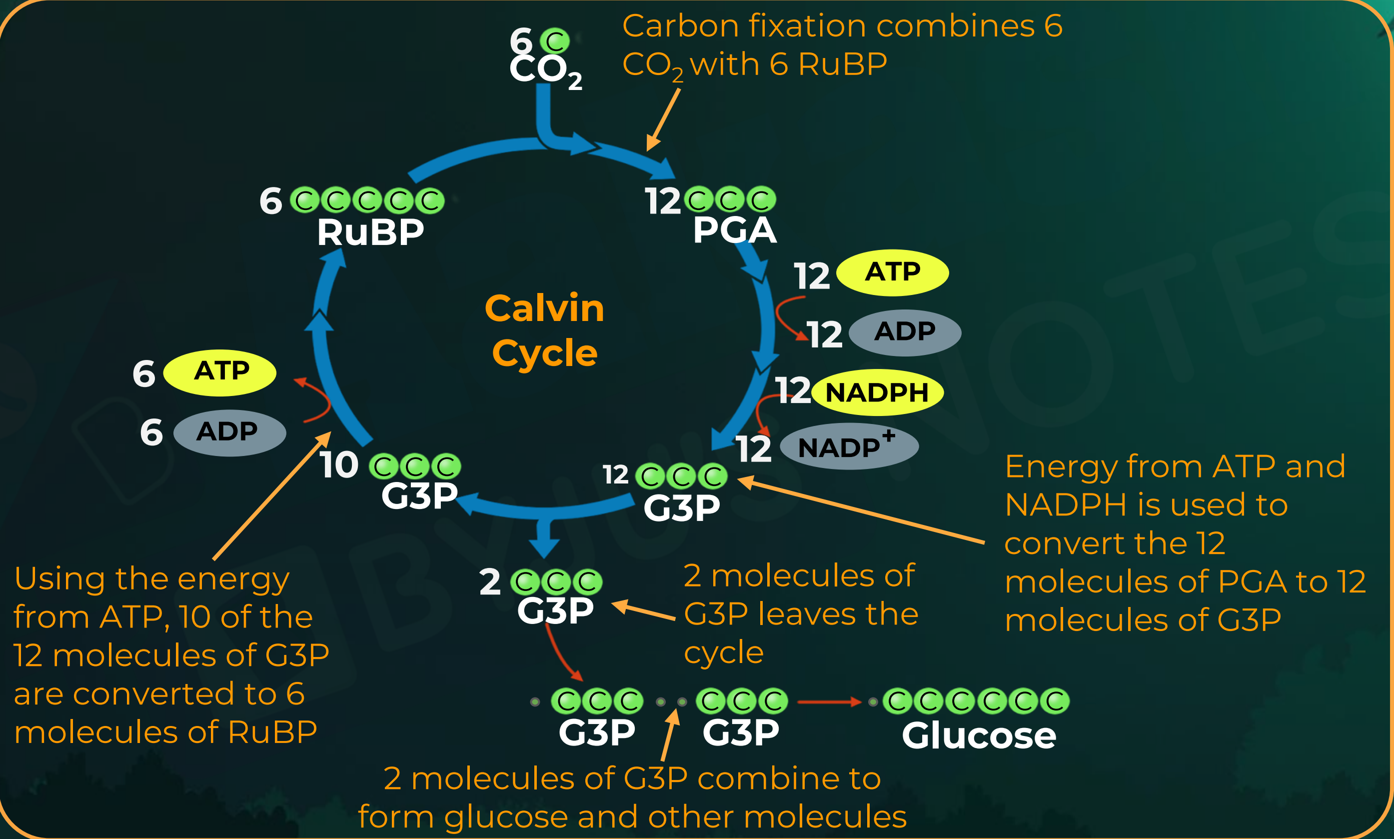
Calvin Cycle



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Calvin Cycle: 6

- In Calvin cycle CO_2 **acceptor molecule is RuBP**.
- The **enzyme** catalyzing this reaction is **RuBP-carboxylase/oxygenase (RuBisCO)**.
- As Calvin cycle takes in only one carbon (as CO_2) at a time, so it takes **six turns of the cycle** to produce a net gain of **six carbons** (i.e., hexose or glucose).
- In this cycle, for formation of one mole of hexose sugar (Glucose), 18 ATP and 12 NADPH2 are used.

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Energy Required

- One molecule of CO_2 entering the Calvin cycle:

In	Out
1 CO_2	No glucose is formed
3 ATP	3 ADP
2 NADPH	2 NADP

- Six CO_2 molecules entering the Calvin cycle:

In	Out
6 CO_2	1 glucose
18 ATP	18 ADP
12 NADPH	12 NADP

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C_4 Plants

C_4 plants exhibit several characteristics that help prevent the oxygenation of RuBisCO.

In C_4 plants, photorespiration does not occur.

Maize

Sugarcane

Sorghum

Amaranthus

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C_4 Plants

Strategies to prevent the oxygenation of RuBisCO

- **Agranal chloroplast-** They are found in the bundle sheath of C_4 plants which prefers cyclic photophosphorylation. This prevents photolysis and photorespiration.
- Interior location of the bundle sheath cells in a plant keeps them at a relatively **lower temperature**.
- Bundle sheath cells have **thicker walls** which prevent the gaseous exchange of oxygen, and protects the RuBisCO.
- **Kranz Anatomy-** Setup in which the **bundle sheath cells** form **several layers around the vascular bundles** and are characterised by **thick walls, no intercellular spaces**, and a large number of chloroplasts.
- The thick walls and no intercellular spaces between the bundle sheath cells **prevent the entry of oxygen and the escape of CO_2**.

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C_4 Pathway

- It is a modified CO_2 fixation pathway.
- The name 'C4 pathway' is derived from the fact that the first stable product is a **4-carbon compound (oxaloacetic acid).**
- It was discovered by two Australian scientists, **Marshall Davidson Hatch** and **Charles Roger Slack**, in 1966.
- Hence, it is also known as the **Hatch-Slack pathway**.
- The C_4 pathway takes place in both mesophyll and **bundle-sheath cells**.

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C_4 Pathway

Phases of C_4 cycle

Initial fixation

- CO_2 acceptor is a 3-carbon molecule **PEP (phosphophenol pyruvate)**.
- The enzyme responsible for this CO_2 fixation is **PEP carboxylase or PEPcase**.
- Mesophyll cells lacks the enzyme RuBisCO.
- Oxaloacetic acid is formed in the cytosol.
- Oxaloacetic acid then gets converted to malic acid or aspartic acid.
- This occurs in mesophyll itself.

Transport- Decarboxylation- Transport

- CO_2 acceptor is a 3-carbon molecule PEP (phosphophenol pyruvate).
- Malic or aspartic acid are translocated to bundle-sheath cells.
- CO_2 is removed from malic acid or aspartic acid to enter the Calvin cycle.
- RuBisCO in bundle-sheath cells is the final acceptor of CO_2.

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C_4 Pathway

Regeneration of PEP

- The 3-carbon molecule is transported back to the mesophyll cells where it is converted to PEP again.
- This is done with the help of cold sensitive enzyme, called **PEP synthetase**.

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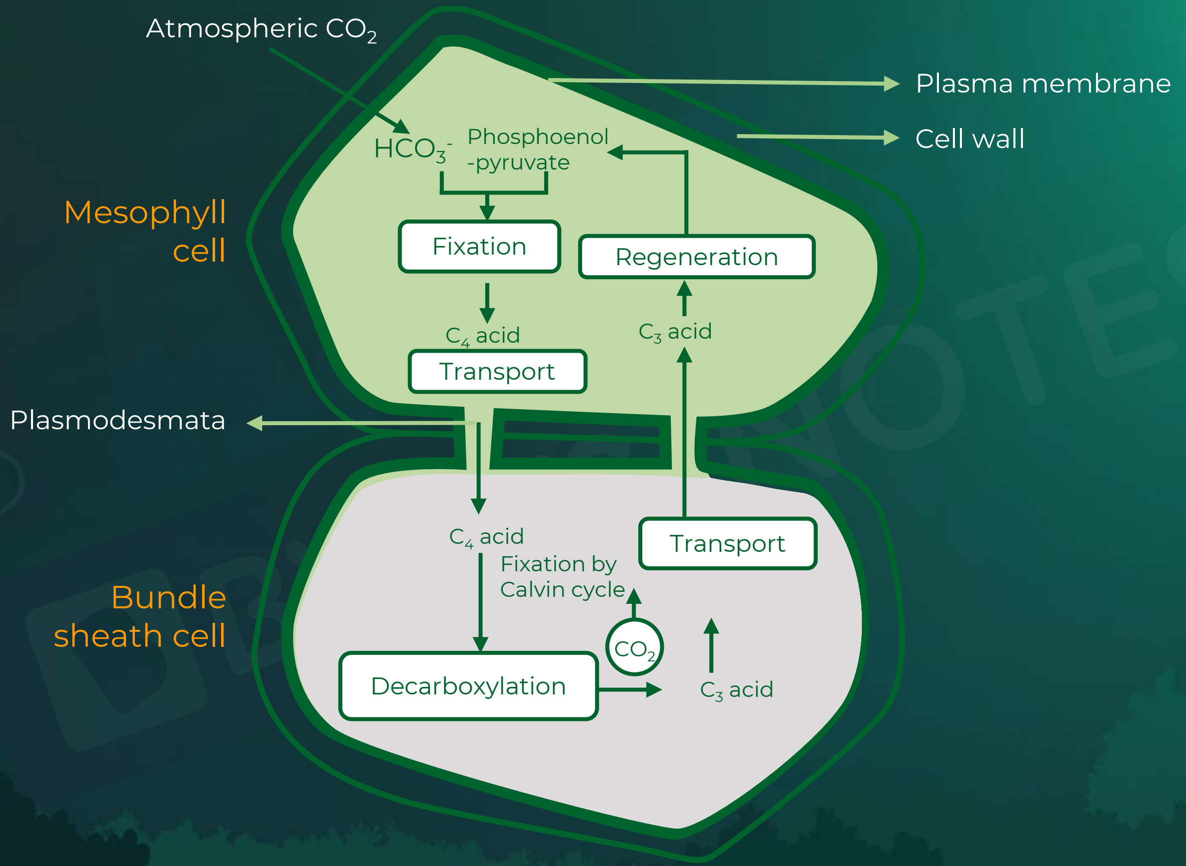
C_4 Pathway



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C_4 Pathway: Output and ATP Consumption

- One glucose molecule contains six carbon atoms. One round of the C_4 cycle fixes one C atom of CO_2 by using 2 ATP.
- Therefore, six turns of the Calvin cycle are needed until 6 C are fixed to produce one molecule of glucose.

	C_3 cycle	C_4 cycle	Total
ATP	• Per C atom fixed = **3 ATP** used	• Per C atom fixed = **2 ATP** used	• Per C atom fixed = 3 + 2 = **5 ATP**
	• For 1 molecule of glucose (6 C-atoms) = 3 x 6 = **18 ATP** used	• For 1 molecule of glucose (6 C-atoms) =2 x 6 = **12 ATP** used	• For 1 molecule of glucose (6 C-atoms) = 18 + 12 = **30 ATP** used
NADPH	**12 NADPH** per glucose molecule used	**No net gain/loss** of NADPH	**12 NADPH** per molecule of glucose used

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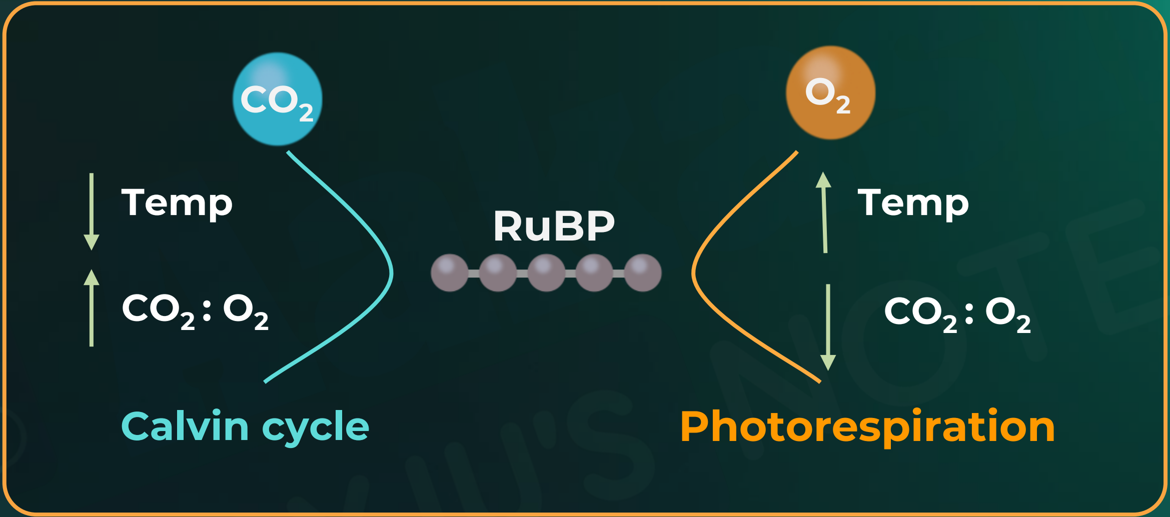
Factors Affecting RuBisCO Binding



RuBisCO facilitates binding of RuBP and CO_2

RuBisCO facilitates binding of RuBP and O_2

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Dual Nature of RuBisCO

RuBisCO

RuBP

CO_2		O_2
Low temperature High CO_2: O_2 ratio		High temperature Low CO_2: O_2 ratio

Calvin cycle

At high relative concentration of carbon dioxide and low temperature, RuBisCO behaves as carboxylase.

Photorespiration

At high relative concentration of oxygen and high temperature, RuBisCO behaves as oxygenase.

Phosphoglycolate is formed, which inhibits the steps of the Calvin cycle.
ATP is consumed, CO_2 is released and no formation of glucose.

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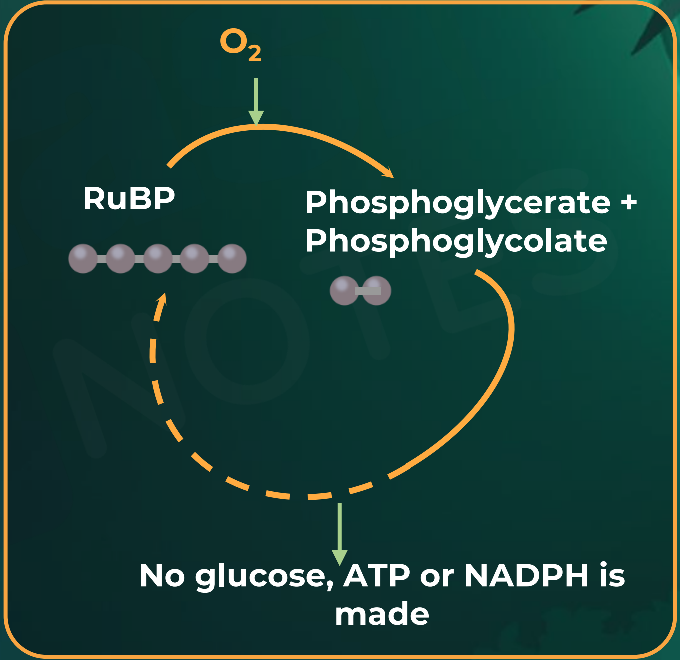
Photorespiration

- In C_3 plants some O_2 does bind to RuBisCO, and hence CO_2 fixation is decreased.
- Here the RuBP instead of being converted to 2 molecules of PGA binds with O_2 to form one molecule of phosphoglycerate and phosphoglycolate (2 Carbon) in a pathway called **photorespiration**.
- In the photorespiratory pathway,
  - No synthesis of sugars, ATP or NADPH.
- Rather it results in the release of CO_2 with the utilisation of ATP.



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Benefits of Photorespiration

Bright light and high temperature

High oxygen and low CO_2

Photorespiration

Causes

Decreased photosynthesis rates

- It removes toxic metabolic intermediates.
- It even protects plants from the damage caused due to excessive light.

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Difference Between C_4 and C_3 Plants

Character	C_4 plants	C_3 plants
1. Primary acceptor	RuBP- 5 carbon compound	Phosphoenol Pyruvate– 3 carbon compound
2. Site of Calvin cycle	Mesophyll cells and bundle-sheath cells	Mesophyll cells
3. First stable photosynthetic product	Oxaloacetic acid, a 4-carbon compound	Phosphoglyceric acid or PGA, a 3-carbon compound
4. Photosynthesis at low concentration of CO_2	Occurs in C_4 plants	Does not occur in the C_3 plants
5. ATP consumed per CO_2 fixed	2	3

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Factors Affecting Photosynthesis

- Photosynthesis is the process by which the plants transform light energy into chemical energy.
- It is under the influence of several factors, both external and internal.
- Blackman’s law of limiting factors is observed when several factors affect any biochemical reaction.
- It was put forward by **F.F. Blackman**, a British plant physiologist.
    - **Blackman’s law of limiting factors**
      If a chemical process is affected by more than one factor, then its rate will be determined by the factor that is nearest to its minimal value. It is the factor that directly affects the process if its quantity is changed.

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External Factors Affecting Photosynthesis

External factors

- Light
- CO_2 concentration
- Water
- Temperature
- O_2

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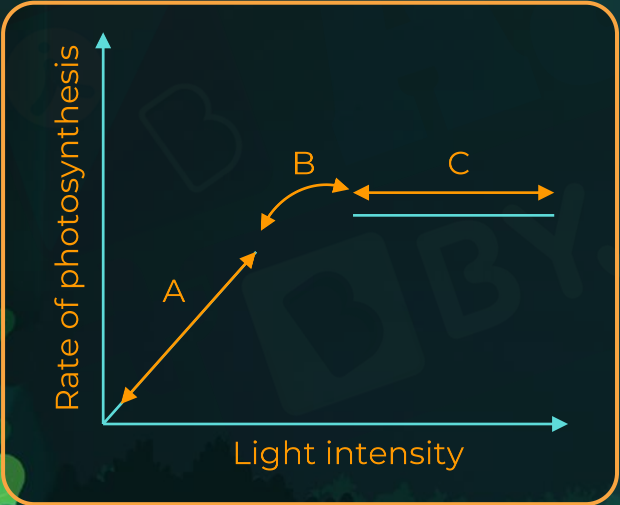
External Factors Affecting Photosynthesis

Light

- Light Intensity
- Light quality
- Duration of exposure



- **Rate of photosynthesis increases as light intensity increases** until it reaches saturation.
  - Saturation occurs at 10% of full sunlight.
- **Blue** and **red** wavelengths are optimum for photosynthesis.
- **Light duration does not affect** the rate of photosynthesis, but it affects the overall photosynthesis.

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External Factors Affecting Photosynthesis

CO_2 concentration

0.03 - 0.04% in atmosphere — CO_2 is a limiting factor

↓

0.05% — Increase in the rate of photosynthesis

↓

>0.05% — Beyond this, the levels can become damaging over long periods

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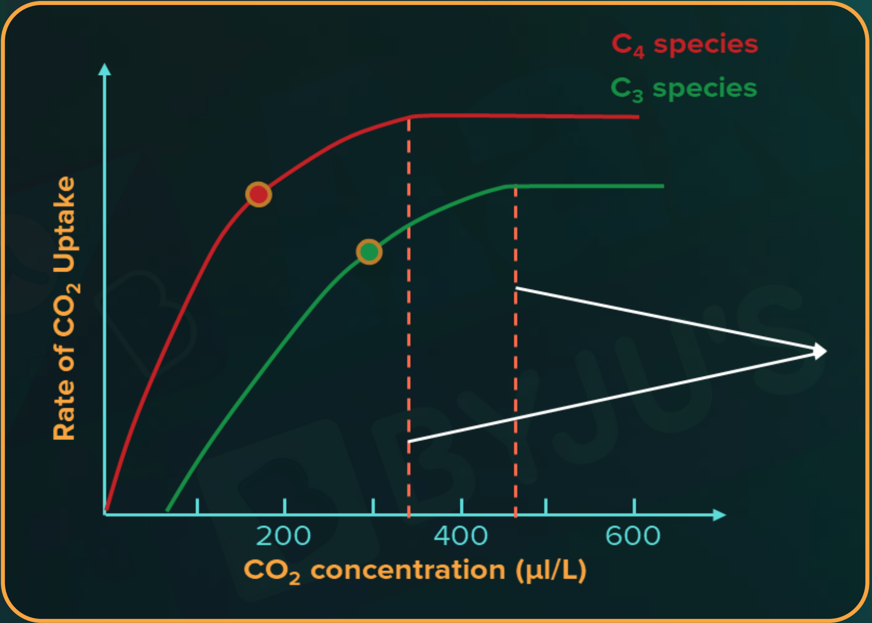
External Factors Affecting Photosynthesis

CO_2 concentration



- As the levels of carbon dioxide increase, the rate of uptake also **increases** in both C_3 and C_4 plants.

Saturation level

- **But after a point**, even as the levels of atmospheric carbon dioxide increase, the rate of assimilation or uptake of CO_2 **does not increase**.

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External Factors Affecting Photosynthesis

Water

The loss of water from the plant as a result of transpiration leads to:

Closed stomata

Prevents exchange of gases like carbon dioxide

Wilted leaves

Reduced surface area
Reduced metabolic activity

Rate of photosynthesis reduced

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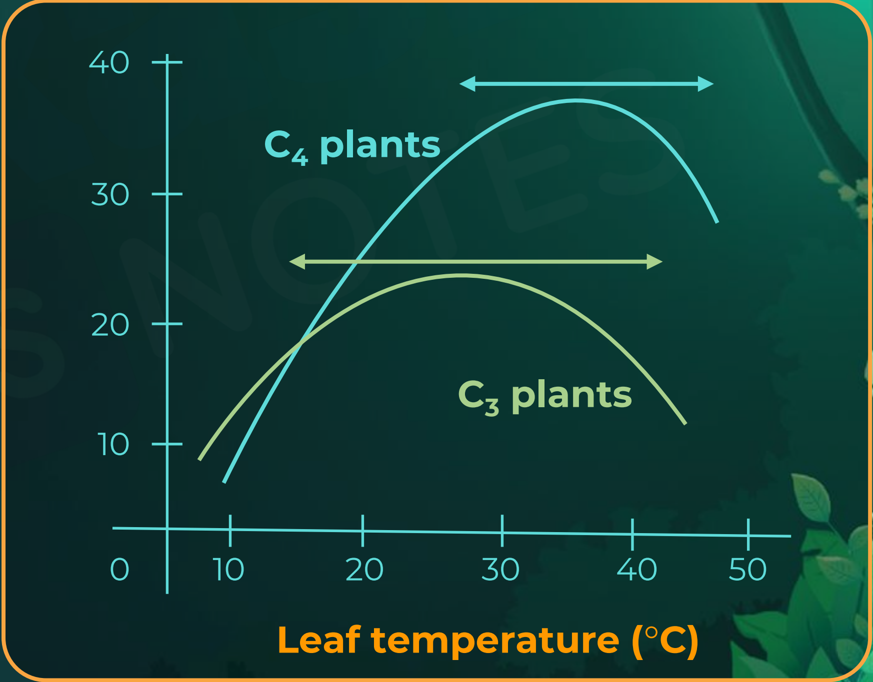
External Factors Affecting Photosynthesis

Temperature

- The light reactions are temperature sensitive but they are affected to a much lesser extent.
- The **dark reactions** being enzymatic are **temperature controlled**.
- The C_4 plants respond to higher temperatures and they show higher rate of photosynthesis.
- **C_3 plants** have much lower temperature optimum.
- Optimum temperature:
  - C_3 plant is 20-25°C.
  - C_4 plant is 30-45°C.



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External Factors Affecting Photosynthesis

Oxygen

- Under conditions involving **high concentrations of oxygen**, RuBisCo competitively binds to oxygen and acts as an oxygenase.
- This is known as the **Warburg effect**.
- This prevents RuBisCO from binding to CO_2.
- Hence, CO_2 fixation is significantly reduced.
- Eventually, **rate of photosynthesis is reduced**.

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Internal Factors Affecting Photosynthesis

- These factors are dependent on the **genetic predisposition** and the **growth of the plant**.

Internal factors

- Number & arrangement of mesophyll cells
- Orientation of leaves
- Age of leaves
- Size of leaves
- Number of leaves
- Amount of chlorophyll
- Photosynthetic products

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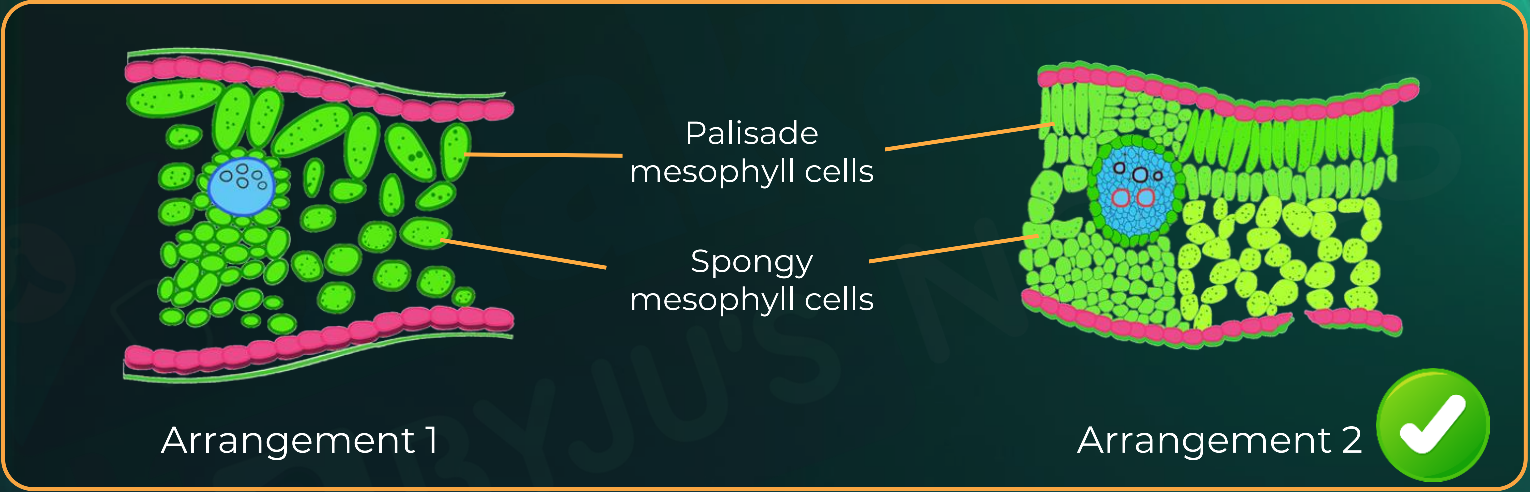
Internal Factors Affecting Photosynthesis

Number and arrangement of mesophyll cells



Arrangement 2 has a greater number of mesophyll cells. Here, the palisade mesophyll cells are arranged such that they **receive the maximum amount of sunlight**.

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Internal Factors Affecting Photosynthesis

Orientation of leaves

Orientation 1

Orientation 2

The petiole is a stalk that attaches the leaf to the stem. The petiole helps in **orienting the leaf to the direction of sunlight**, thus improving the rate of photosynthesis.

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Internal Factors Affecting Photosynthesis

Age of leaves

Young leaves

Mature leaves

Old leaves

Rate of photosynthesis depends on the age of the leaves. The rate of photosynthesis in too young and too old leaves is lower than that of mature leaves.

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Internal Factors Affecting Photosynthesis

Size of leaves

Big leaves

Small leaves

Bigger leaves means **more surface area**, which means **more chlorophyll** and thus **more photosynthesis**.

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Internal Factors Affecting Photosynthesis

Number of leaves

Many leaves

Few leaves

Plants with **more leaves** would have **more chlorophyll** and hence will be able to sustain a much **higher rate of photosynthesis**.
That does not mean that the plants with fewer leaves do not photosynthesise efficiently. Few or more leaves is simply an adaptation.

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Internal Factors Affecting Photosynthesis

Amount of chlorophyll

Absence of chlorophyll = 🚫 Photosynthesis

- The non-green parts of variegated leaves (e.g., Croton), do not have chlorophyll.
- **Photosynthetic number** is the amount of carbon dioxide (in gm) assimilated by one gram of chlorophyll in an hour.
- It was observed a direct relationship between the chlorophyll content of a leaf and the rate of photosynthesis.
- If all other factors are favourable, increased **chlorophyll leads to an increase in photosynthesis**.

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Internal Factors Affecting Photosynthesis

Photosynthetic products

$$\text{Carbon dioxide} + \text{Water} \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} \text{Glucose} + \text{Oxygen}$$

- Accumulation of carbohydrate causes **feedback inhibition** of photosynthesis.
- **Rate of photosynthesis decreases** because concentration of photosynthetic products in the cells increases the rate of respiration.

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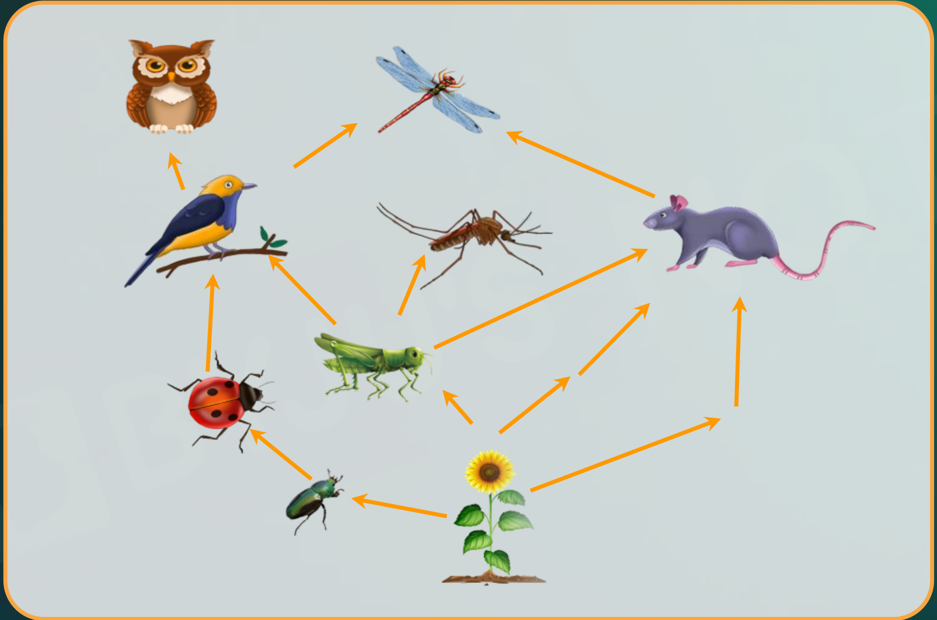
Significance of Photosynthesis

Photosynthesis is **essential for the existence of all life on Earth**. It serves a crucial role in the **food chain**.



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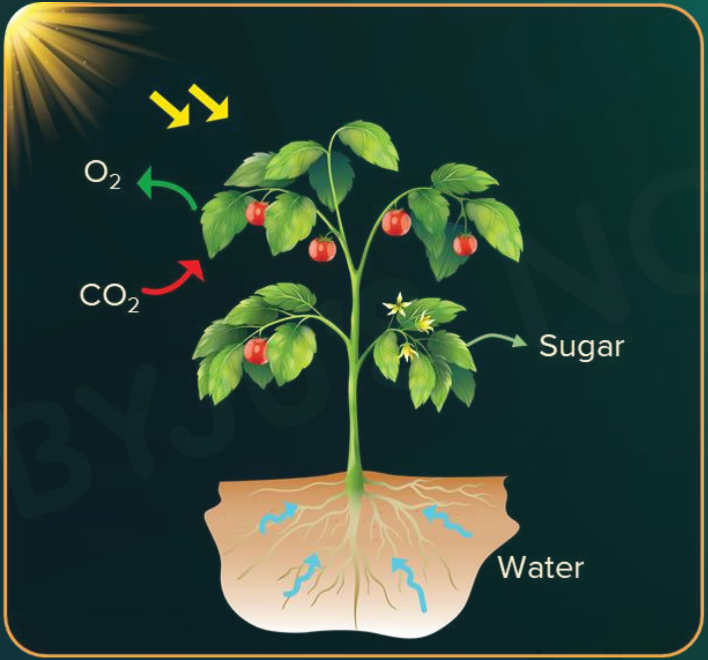
Significance of Photosynthesis

Photosynthesis is also responsible for the **production of oxygen**, which is needed by most organisms for their survival.



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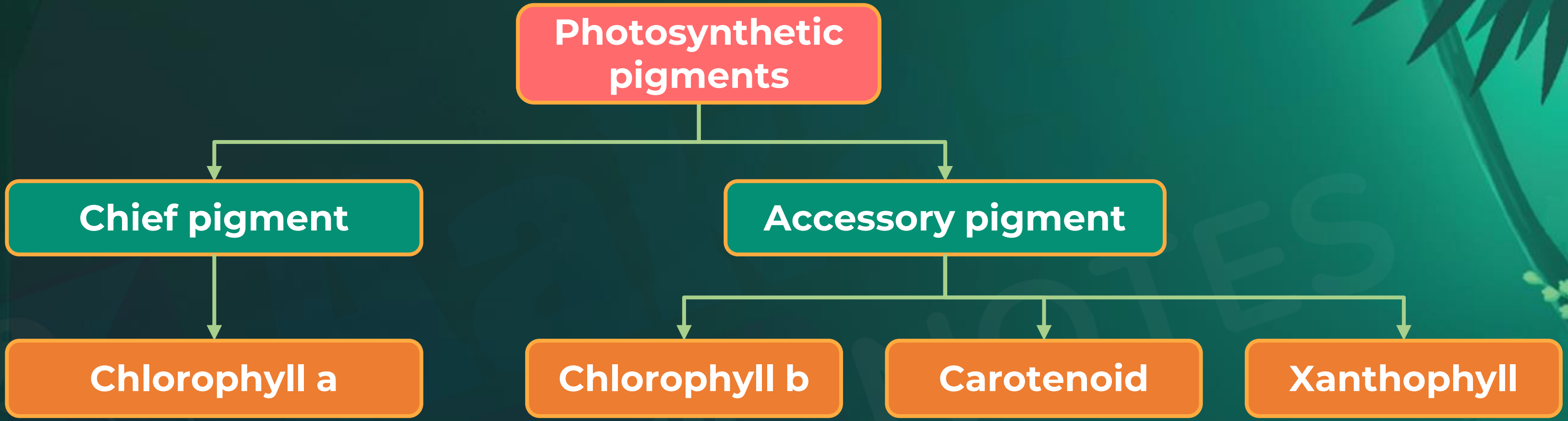
Summary



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Summary

Cyclic photophosphorylation	Non-cyclic photophosphorylation
Synthesis of ATP during the light reaction of photosynthesis by cyclic passage of electrons to and from P700.	Synthesis of ATP during the light reaction of photosynthesis in which an electron donor is required and oxygen is produced as by product.
Occurs in isolated chloroplasts and photosynthetic bacteria.	Occurs in higher plants, algae and cyanobacteria.
Occurs in anoxygenic photosynthesis (No oxygen evolved).	Occurs in oxygenic photosynthesis (Oxygen evolved).
Final electron acceptor is P_{700}.	Final electron acceptor is NADP+.

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Summary

Cyclic photophosphorylation	Non-cyclic photophosphorylation
Electrons move in a cyclic pattern	Electrons in a linear pattern, also known as the Z scheme
Only photosystem I is involved	Both photosystem I and II are involved
Electrons are first - expelled from the reaction centre of PS I	Electrons are first - expelled from the reaction centre of PS II
Electrons return to the P700 after passing through ETS	Electrons return to the P680 (after photolysis of water) and are accepted by NADP+
Photolysis does not occur	Photolysis occurs

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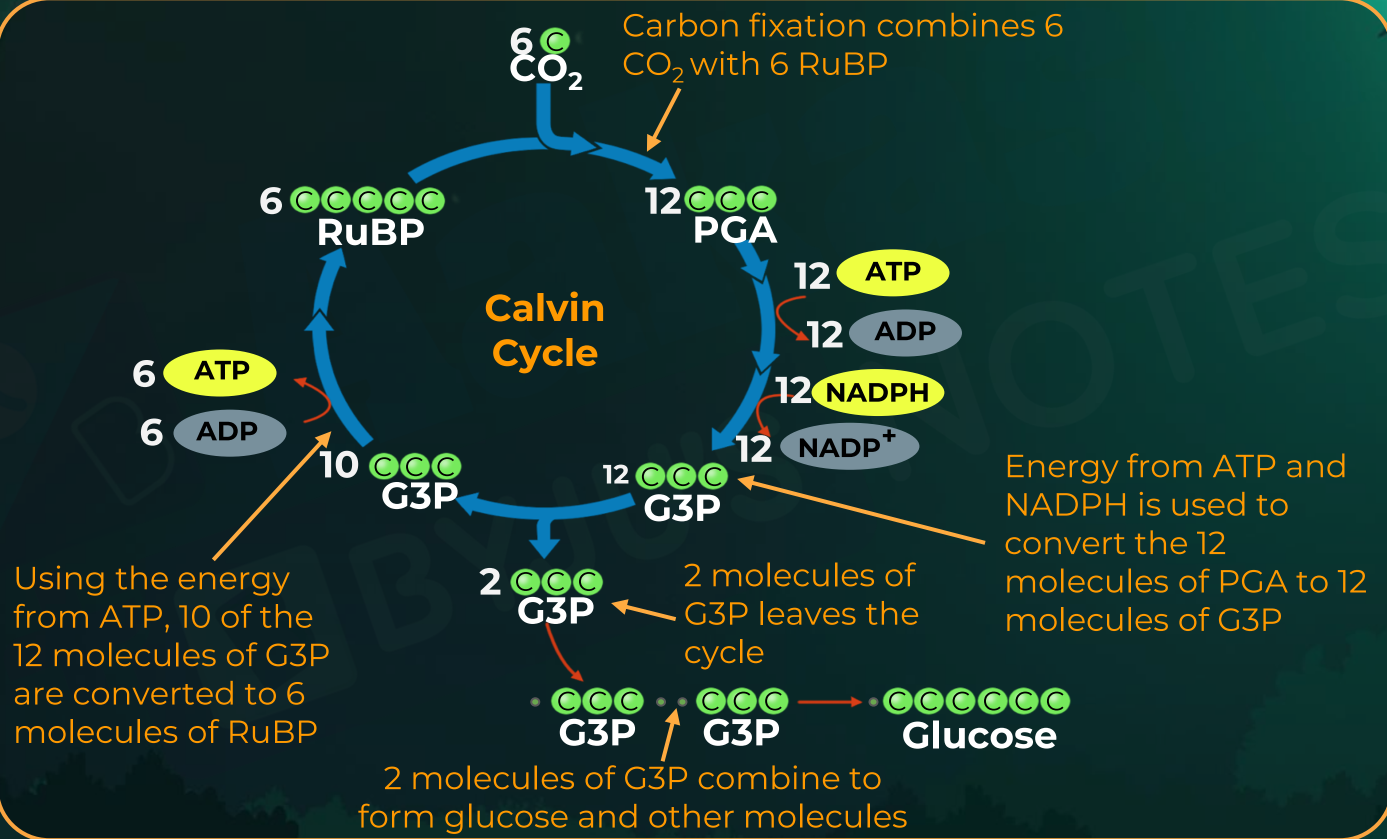
Summary



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Summary

RuBisCO

CO_2 — RuBP — O_2

Low temperature
High CO_2: O_2 ratio

High temperature
Low CO_2: O_2 ratio

Calvin cycle

At high relative concentration of carbon dioxide and low temperature, RuBisCO behaves as carboxylase.

Photorespiration

At high relative concentration of oxygen and high temperature, RuBisCO behaves as oxygenase.

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Summary

Difference Between C_4 and C_3 Plants

Character	C_4 plants	C_3 plants
1. Primary acceptor	RuBP- 5 carbon compound	Phosphoenol Pyruvate– 3 carbon compound
2. Site of Calvin cycle	Mesophyll cells and bundle-sheath cells	Mesophyll cells
3. First stable photosynthetic product	Oxaloacetic acid, a 4-carbon compound	Phosphoglyceric acid or PGA, a 3 carbon compound
4. Photosynthesis at low concentration of CO_2	Occurs in C_4 plants	Does not occurs in the C_3 plants
5. ATP consumed per CO_2 fixed	2	3

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Summary

Factors affecting photosynthesis

External factors
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- Water
- Temperature
- O_2

Internal factors
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