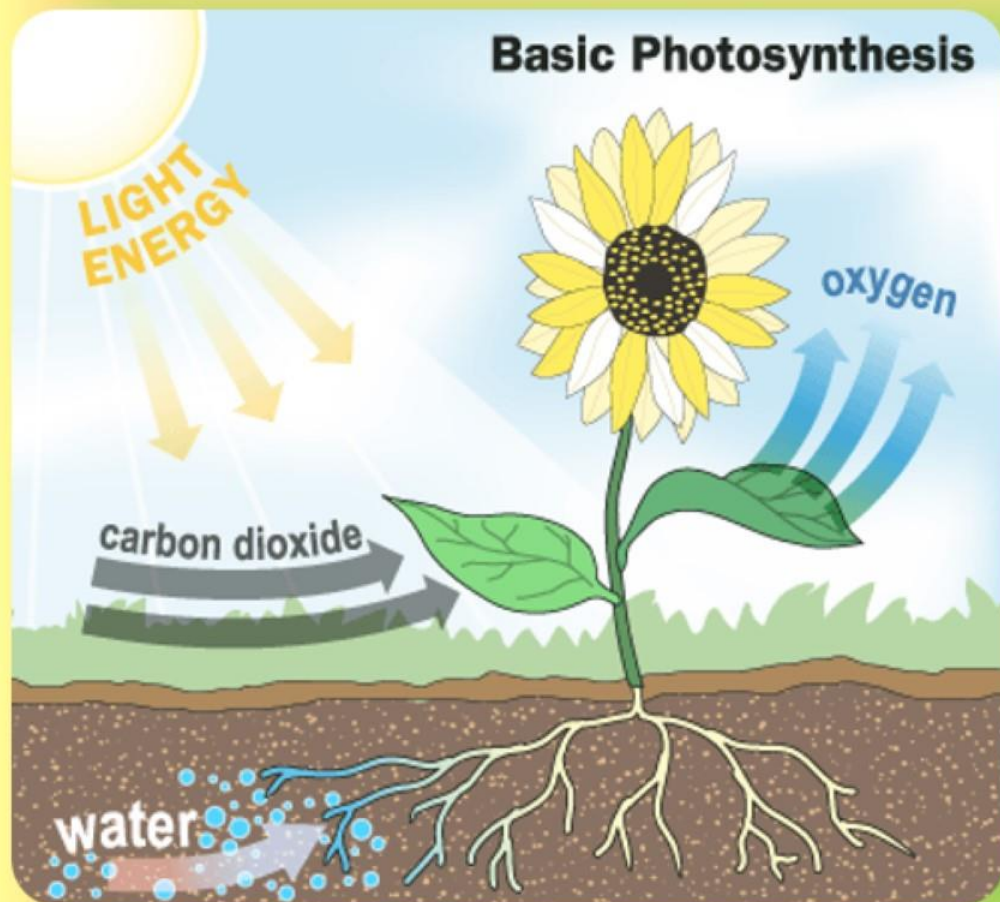


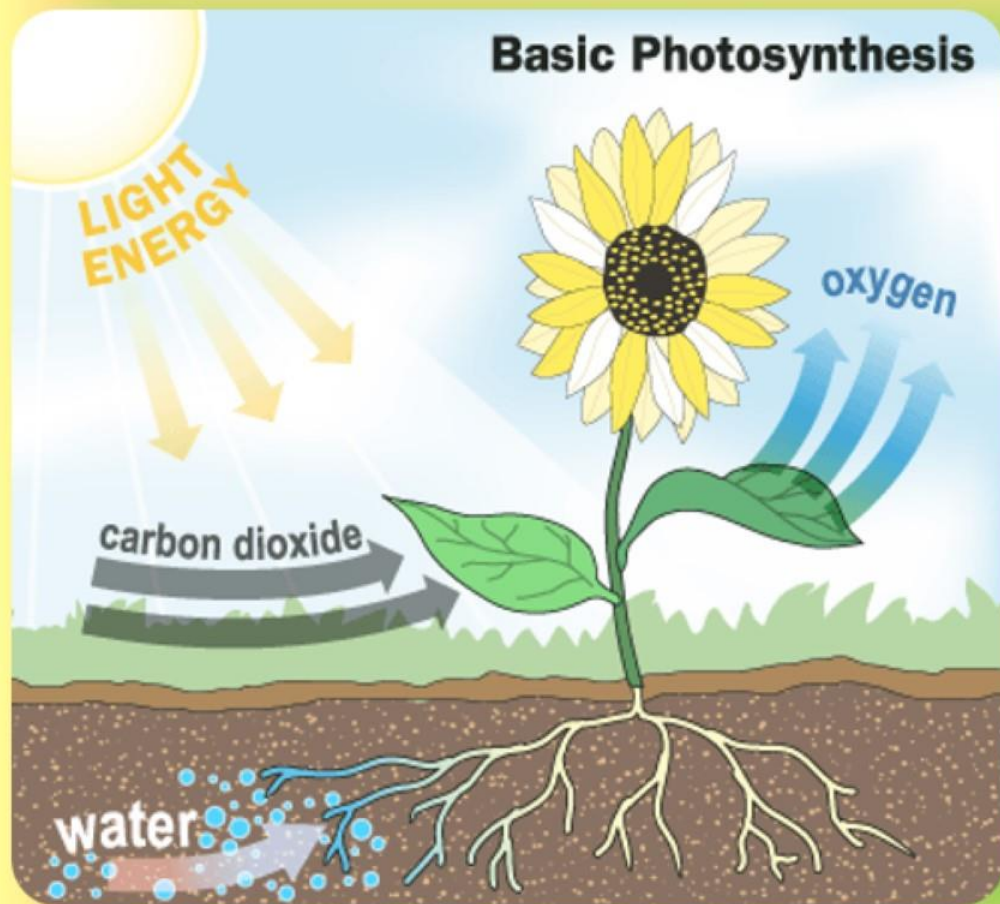
PHOTOSYNTHESIS

Basic Photosynthesis



- Photosynthesis is a **physico-chemical process** by which green plants use light energy (solar energy) to synthesise organic compounds.
- It is the basis of life on earth.
- Ultimately, all living forms depend on sunlight for energy.

Basic Photosynthesis



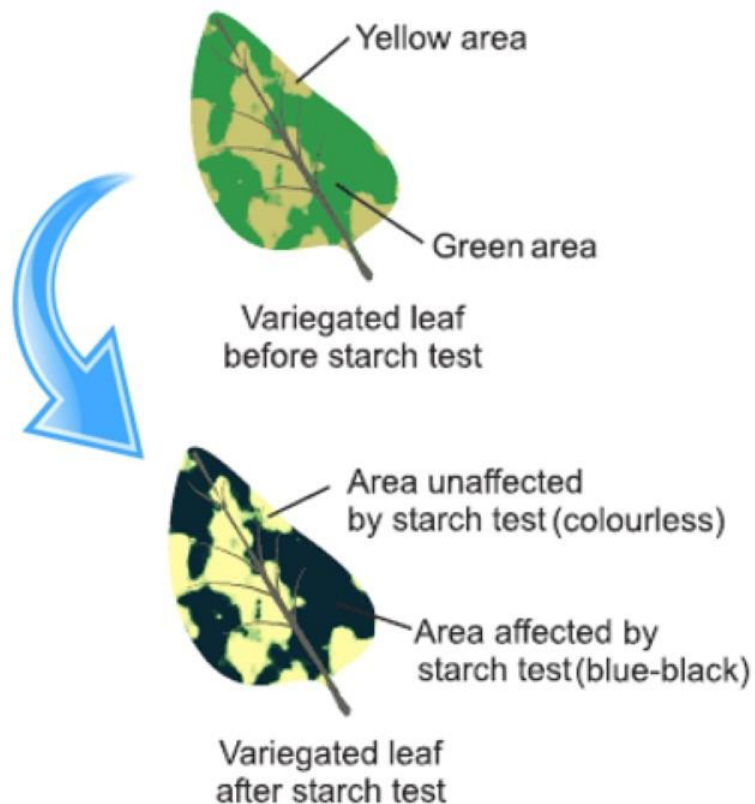
Importance of Photosynthesis

- ✓ It is the primary source of all food on earth.
- ✓ It releases oxygen into the atmosphere.



EXPERIMENTS RELATED WITH PHOTOSYNTHESIS

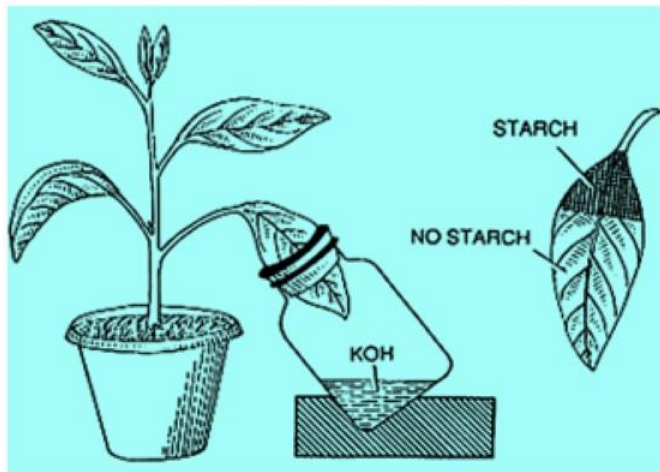
EXPERIMENTS RELATED WITH PHOTOSYNTHESIS



1. Variegated leaf experiment

- Take a **variegated leaf** (or leaf partially covered with black paper) that was exposed to light.
- Test the leaves for **starch**.
- It shows that photosynthesis occurs **only in green parts** of the leaves in presence of light.

EXPERIMENTS RELATED WITH PHOTOSYNTHESIS



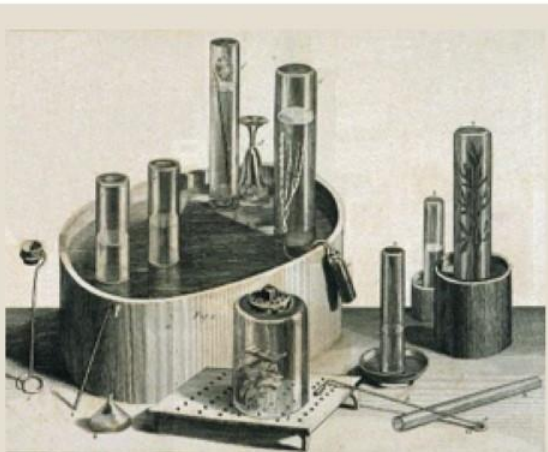
2. Half-leaf experiment

- A part of a leaf is enclosed in a test tube containing **KOH soaked cotton** (which absorbs CO_2).
- The other half of leaf is exposed to air.
- Place this setup in light for some time.
- Test the leaf for presence of starch.
- **Exposed part** shows **positive for starch** and **portion in the tube** shows **negative**.
- This proves that **CO_2 is required for photosynthesis**.

EXPERIMENTS RELATED WITH PHOTOSYNTHESIS

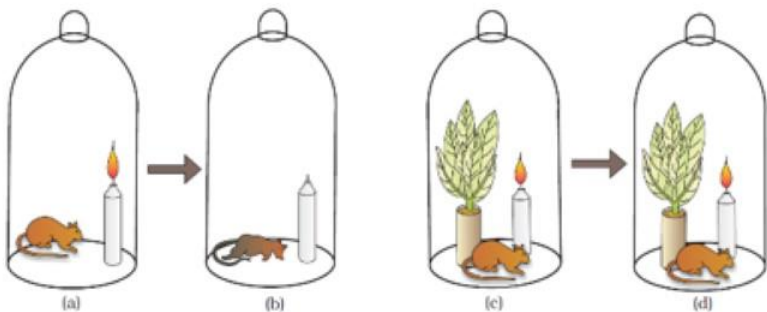


Equipment
used by
Joseph
Priestley



Experiments by Joseph Priestley (1770)

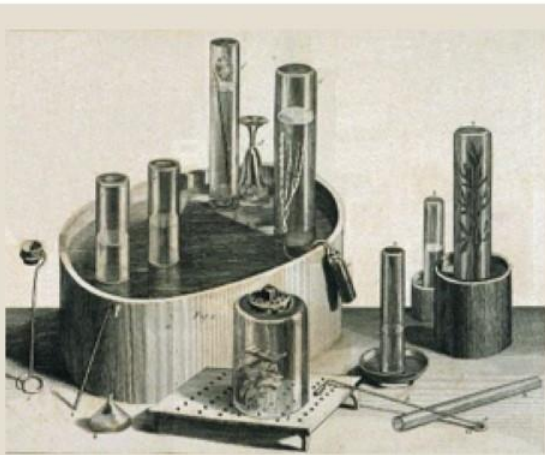
- **Priestley** performed experiments to prove the role of air in the growth of green plants.
- He discovered **oxygen** in 1774.
- He observed that a candle burning in a closed bell jar gets extinguished. Similarly, a mouse suffocated in closed jar.
- He concluded that a burning candle or a breathing animal damage the air.



EXPERIMENTS RELATED WITH PHOTOSYNTHESIS

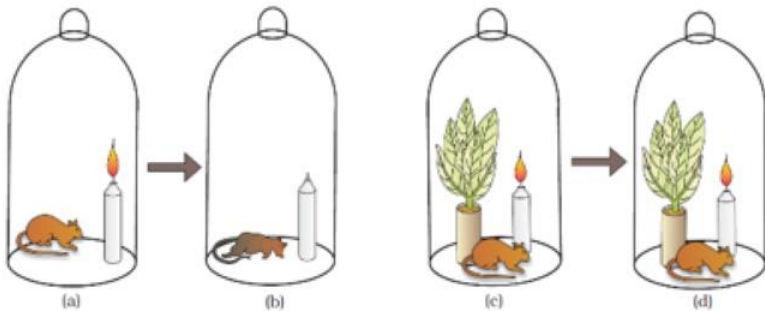


Equipment
used by
Joseph
Priestley



Experiments by Joseph Priestley (1770)

- He placed a mint plant in the bell jar.
- He found that the mouse stayed alive and the candle continued to burn.
- He hypothesised that **plants restore to the air whatever breathing animals and burning candles remove.**

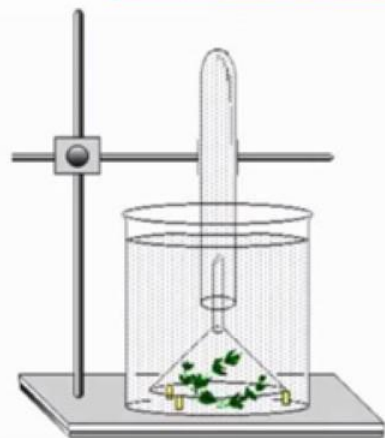


EXPERIMENTS RELATED WITH PHOTOSYNTHESIS



Experiments by Jan Ingenhousz (1730-1799)

- He conducted the same experiment by placing it once in the dark and once in the sunlight.
- He showed that **sunlight is essential to the plant for purifying the air.**
- He repeated this experiment with an aquatic plant. It showed that **in bright sunlight, small bubbles were formed around green parts while in the dark they did not.**
- Later he identified these bubbles to be of **oxygen**. Thus he showed that **only the green part of plants release O_2 .**



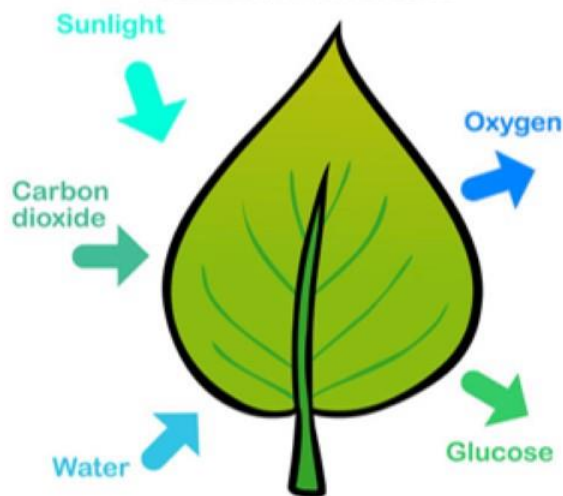
EXPERIMENTS RELATED WITH PHOTOSYNTHESIS



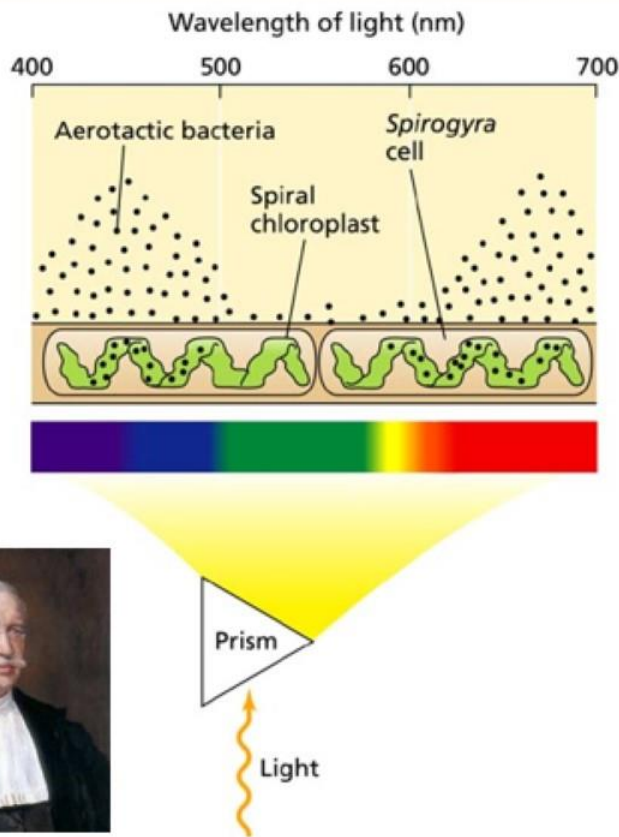
Experiments by Julius von Sachs (1854)

He proved that

- ✓ **Glucose is produced when plants grow and it is usually stored as starch.**
- ✓ **Chlorophyll is located in special bodies (chloroplasts).**
- ✓ **Glucose is made in the green parts of plants.**



EXPERIMENTS RELATED WITH PHOTOSYNTHESIS

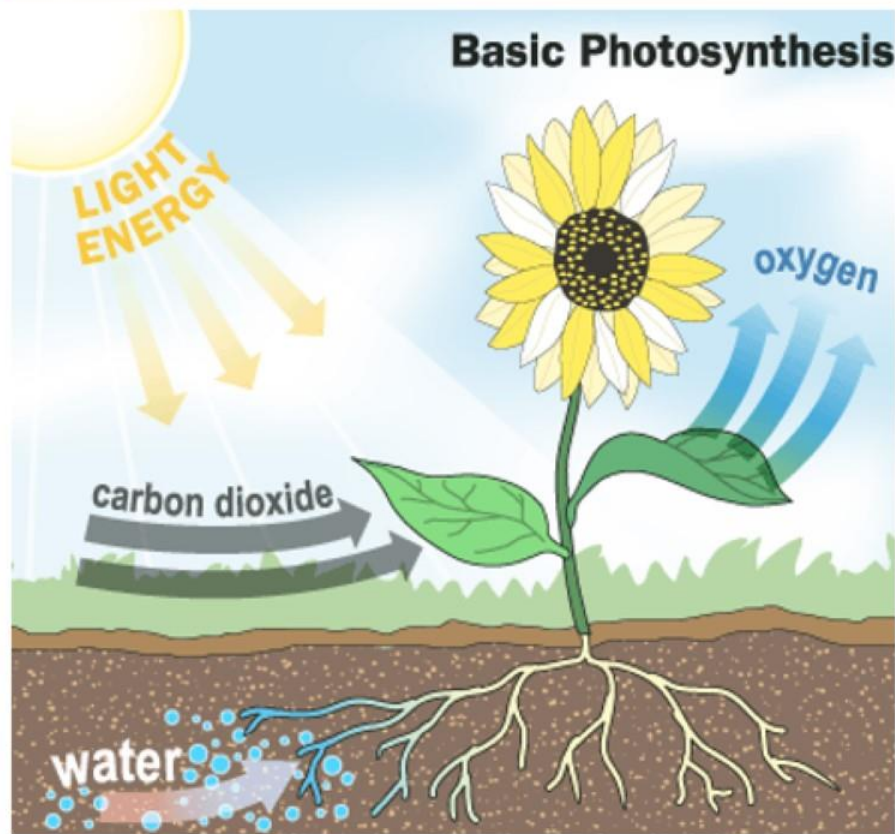


Experiments by T.W Engelmann (1843 – 1909)

- He split the light using a prism into its spectral components and illuminated a **green alga (*Cladophora*)** placed in a suspension of aerobic bacteria. The bacteria were used to detect the sites of O_2 evolution.
- He observed that the **bacteria accumulated mainly in the region of blue & red light** of the split spectrum.
- It was the first described **action spectrum** of photosynthesis. It resembles the absorption spectra of chlorophyll *a* and *b*.

EXPERIMENTS RELATED WITH PHOTOSYNTHESIS

Basic Photosynthesis



- By the middle of 19th century, it is discovered that **plants use light energy to make carbohydrates from CO₂ & H₂O.**
- Empirical equation of the process of photosynthesis is



- Where, [CH₂O] represents a carbohydrate (e.g., glucose).

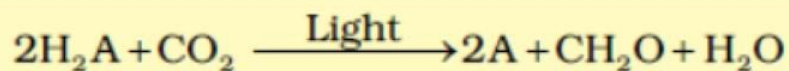
EXPERIMENTS RELATED WITH PHOTOSYNTHESIS



Purple and green bacteria

Experiments by Cornelius van Niel (1897-1985)

- **Van Niel** (microbiologist) conducted some studies in **purple and green bacteria**.
- He demonstrated that photosynthesis is a light-dependent reaction in which hydrogen from a suitable oxidisable compound reduces CO_2 to carbohydrates.
- This can be expressed by:



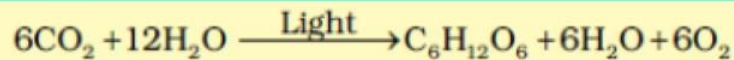
EXPERIMENTS RELATED WITH PHOTOSYNTHESIS

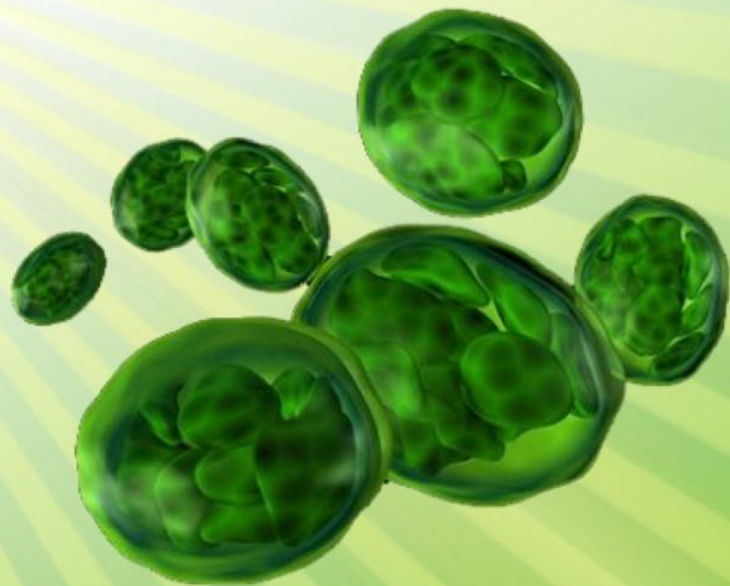


Purple and green bacteria

Experiments by Cornelius van Niel (1897-1985)

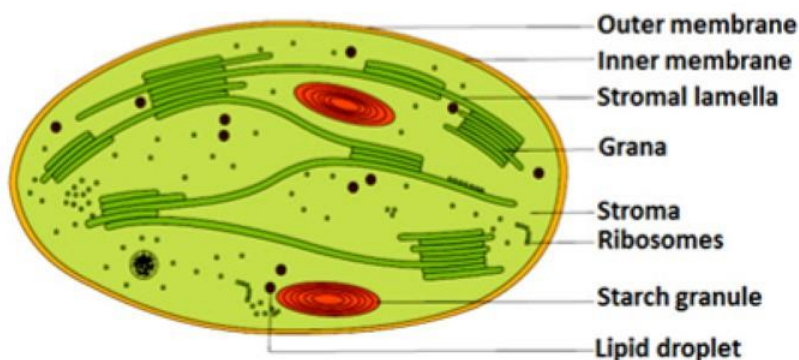
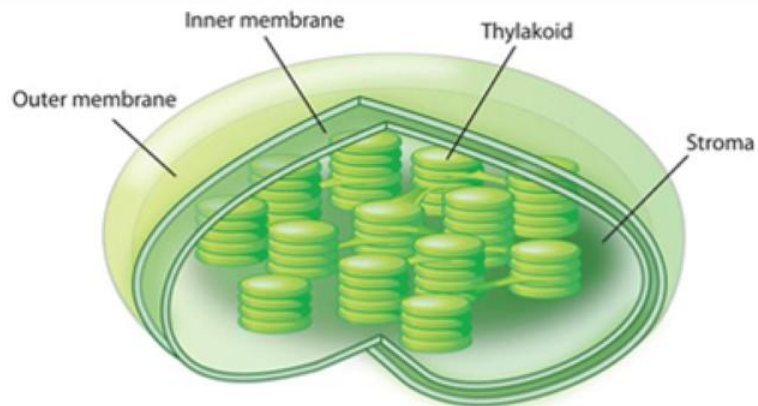
- In plants, **H₂O is the hydrogen donor** and is oxidised to O₂.
- Purple & green sulphur bacteria use **H₂S as H-donor**. So the 'oxidation' product is sulphur or sulphate and no O₂ is produced.
- Thus, he inferred that the O₂ evolved by green plant comes from H₂O, not from CO₂. This was later proved by using radio-isotopic techniques.
- Therefore overall correct equation for photosynthesis is:





PHOTOSYNTHESIS: SITE & PIGMENTS

PHOTOSYNTHESIS: SITE AND PIGMENTS

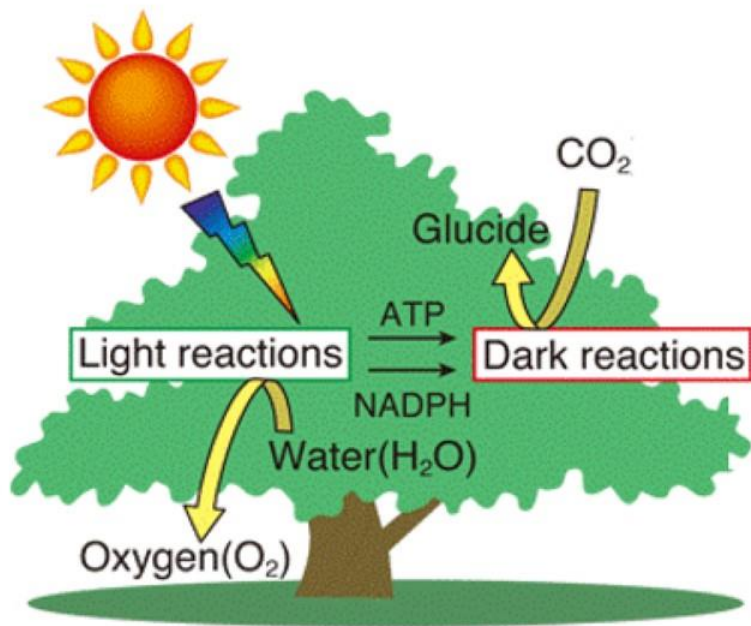


Chloroplasts

- Photosynthesis takes place in green leaves and other green parts of the plants.
- **Chloroplasts** present in the walls of **mesophyll cells** of leaves. It helps to get optimum quantity of incident light.
- Chloroplast contains a **membranous system**. It consists of **grana**, **stroma lamellae** and **fluid stroma**.
- Each granum is a group of membrane-bound sacs called **thylakoids (lamellae)**. They contain leaf pigments.

PHOTOSYNTHESIS: SITE AND PIGMENTS

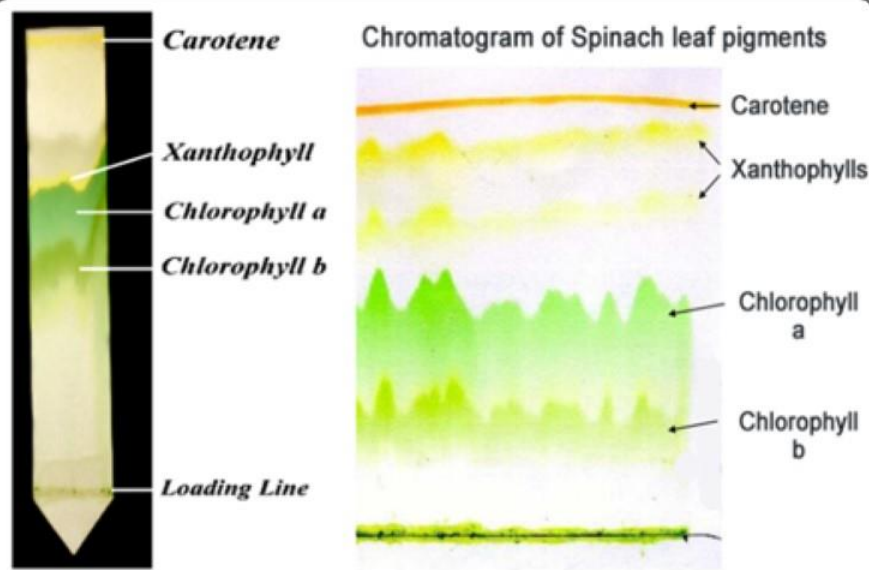
Chloroplasts



- The **membrane system** traps light energy and synthesise ATP and NADPH. It is called **light reactions**.
- In **stroma**, enzymatic reactions incorporate CO₂ into the plant for synthesizing sugar, which in turn forms starch. It is called **dark reactions**. It does not mean that they occur in darkness or that they are not light dependent.

PHOTOSYNTHESIS: SITE AND PIGMENTS

PIGMENTS INVOLVED IN PHOTOSYNTHESIS



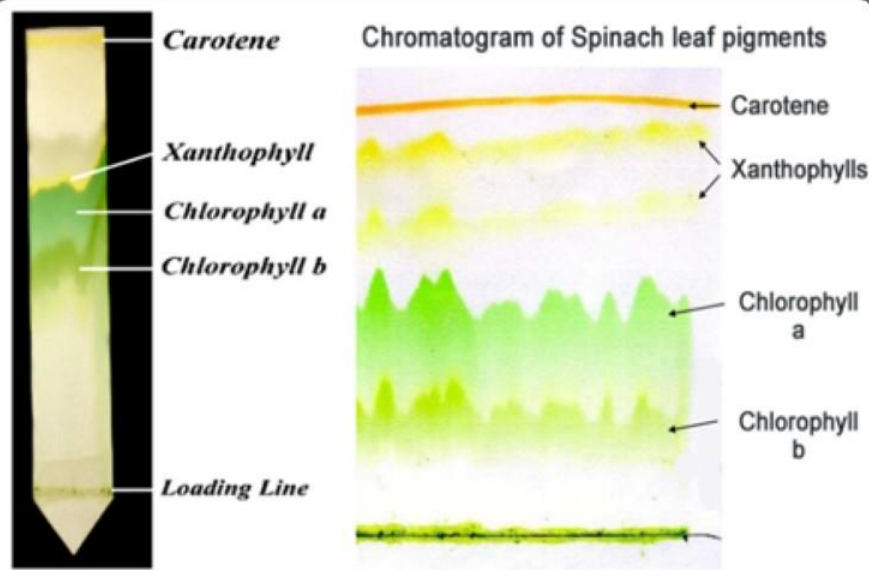
Separation of Pigments by Paper Chromatography



- **Pigments** are substances that have ability to absorb light at specific wavelengths.
- **Chromatography** shows the following leaf pigments in **chromatogram**:
 - **Chlorophyll a**: Bright or blue green.
 - **Chlorophyll b**: Yellow green.
 - **Xanthophylls**: Yellow.
 - **Carotenoids**: Yellow to yellow-orange.

PHOTOSYNTHESIS: SITE AND PIGMENTS

PIGMENTS INVOLVED IN PHOTOSYNTHESIS



Separation of Pigments by Paper Chromatography



- **Chlorophyll *b*, Xanthophylls & Carotenoids** are Accessory pigments.

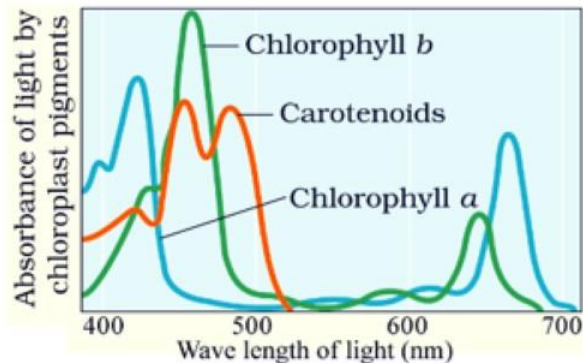
Functions of accessory pigments

- They absorb light at different wavelength and transfer the energy to chlorophyll *a*.
- They protect chlorophyll *a* from photo-oxidation.

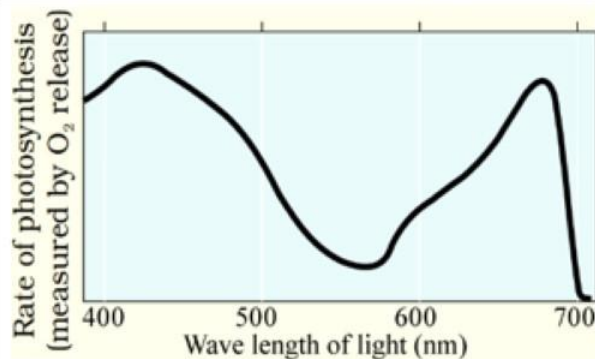
PHOTOSYNTHESIS: SITE AND PIGMENTS

PIGMENTS INVOLVED IN PHOTOSYNTHESIS

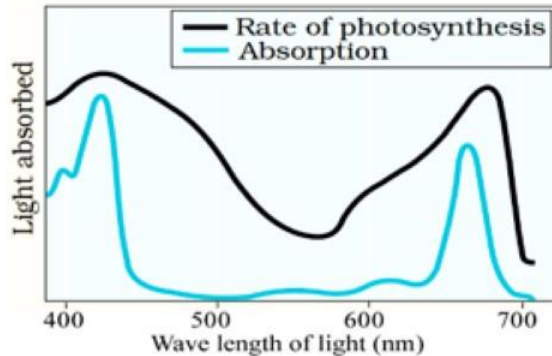
- The **absorption spectrum & action spectrum** coincide closely showing that photosynthesis is maximum at the **blue & red regions** of the spectrum.
- The graphs also show that chlorophyll *a* is the chief pigment associated with photosynthesis.



Graph showing absorption spectrum of chlorophyll *a*, *b* & carotenoids.



Graph showing action spectrum of photosynthesis.

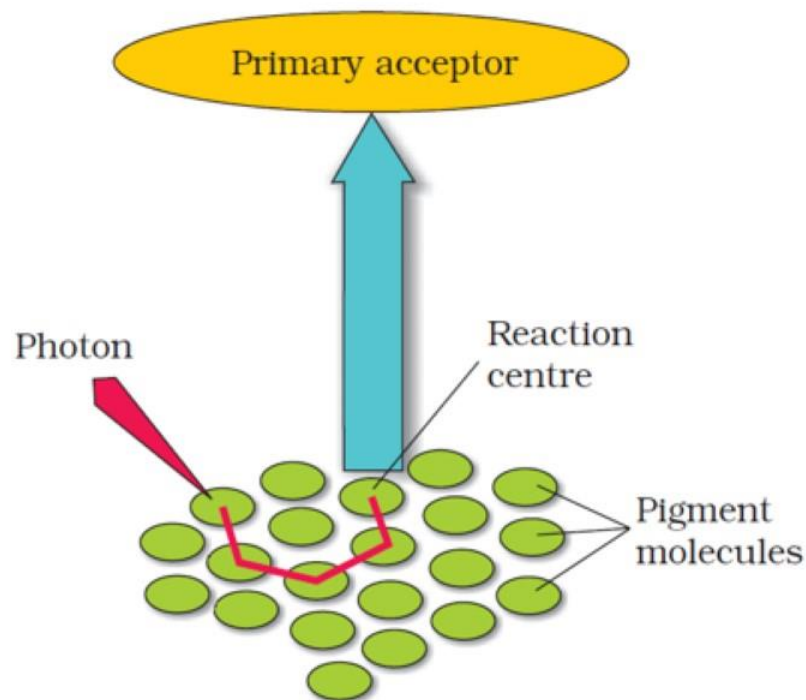


Graph showing action spectrum superimposed on absorption spectrum of chlorophyll *a*.

PHOTOSYNTHESIS: SITE AND PIGMENTS

Photosystems

- Pigments are organised into two **Photosystems** called **Photosystem I (PSI) & Photosystem II (PSII)**. These are named in the sequence of their discovery.
- Each photosystem has a **chlorophyll a** and **accessory pigments** bound by proteins.

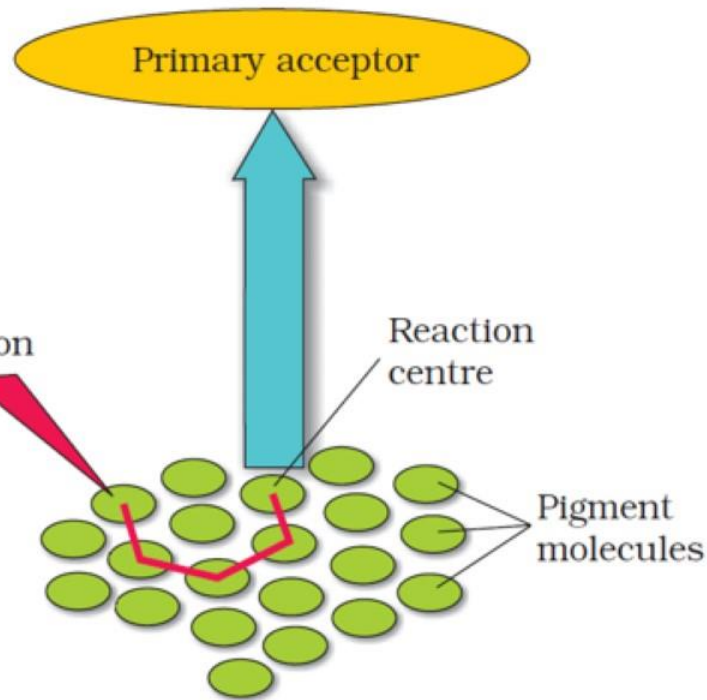


LIGHT HARVESTING COMPLEX

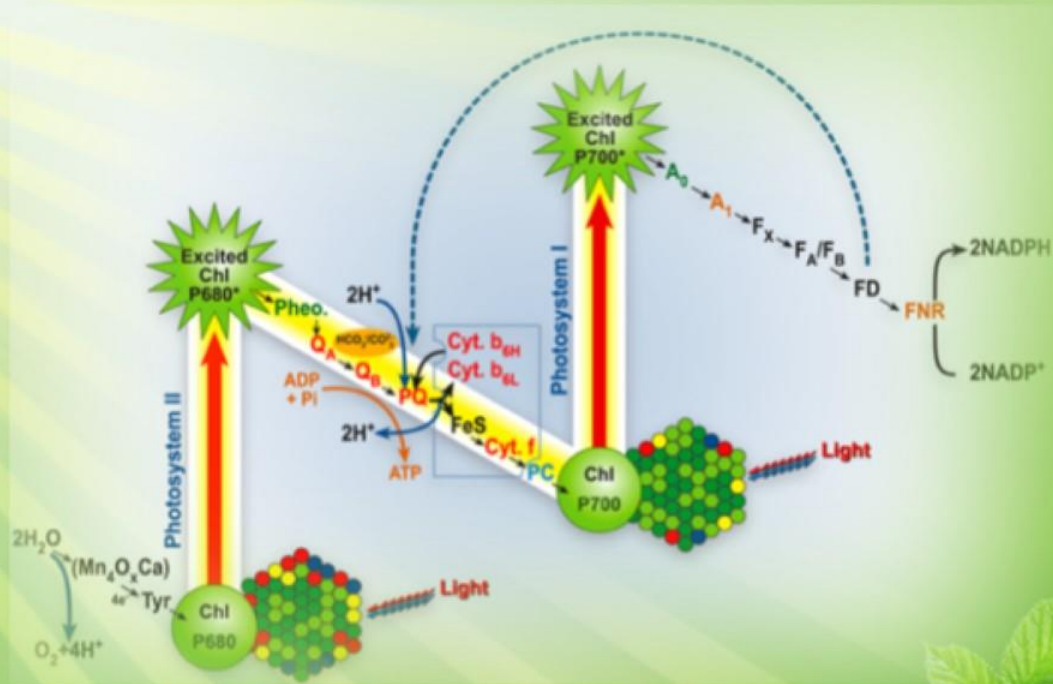
PHOTOSYNTHESIS: SITE AND PIGMENTS

Photosystems

- All pigments (except one molecule of chlorophyll *a*) form a **light harvesting complex (LHC or antennae)**.
- Single **chlorophyll *a*** acts as **reaction centre**.
- In **PS I**, the reaction centre absorbs light at **700 nm**, and so called **P700**.
- In **PS II**, the reaction centre absorbs light at **680 nm**, and so called **P680**.

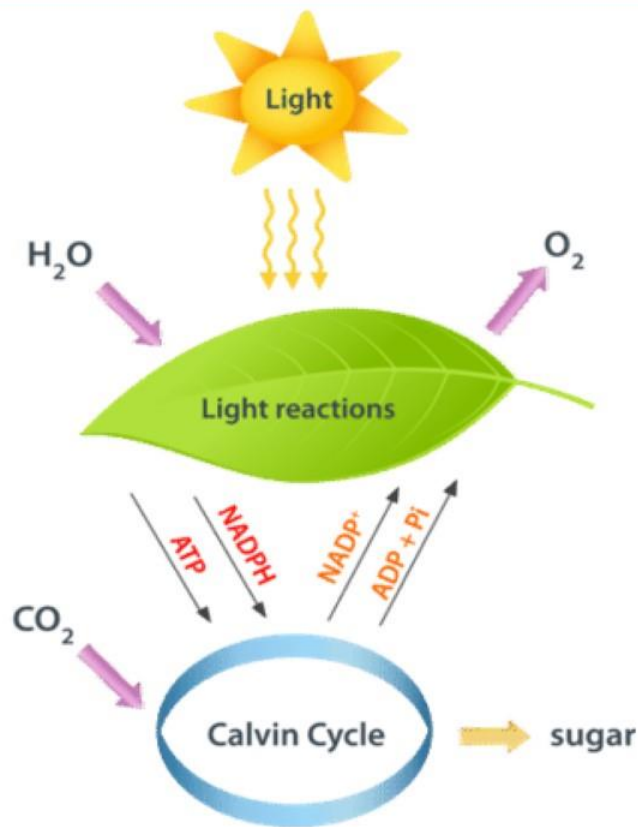


LIGHT HARVESTING COMPLEX



LIGHT REACTION OR PHOTOCHEMICAL PHASE

LIGHT REACTION (PHOTOCHEMICAL PHASE)

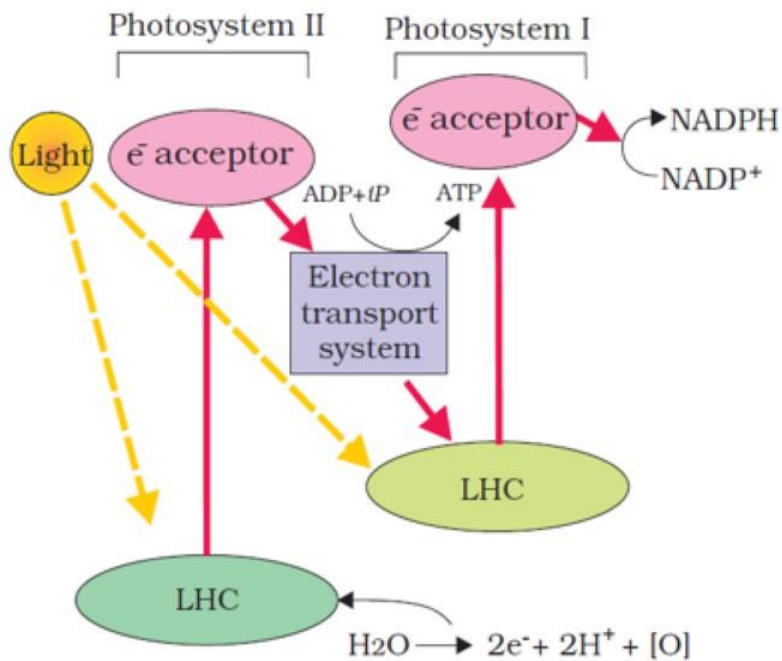


Light reactions include

- ☐ Light absorption
- ☐ Water splitting
- ☐ Oxygen release
- ☐ Formation of ATP & NADPH

ATP & NADPH: High-energy chemical intermediates.

LIGHT REACTION (PHOTOCHEMICAL PHASE)

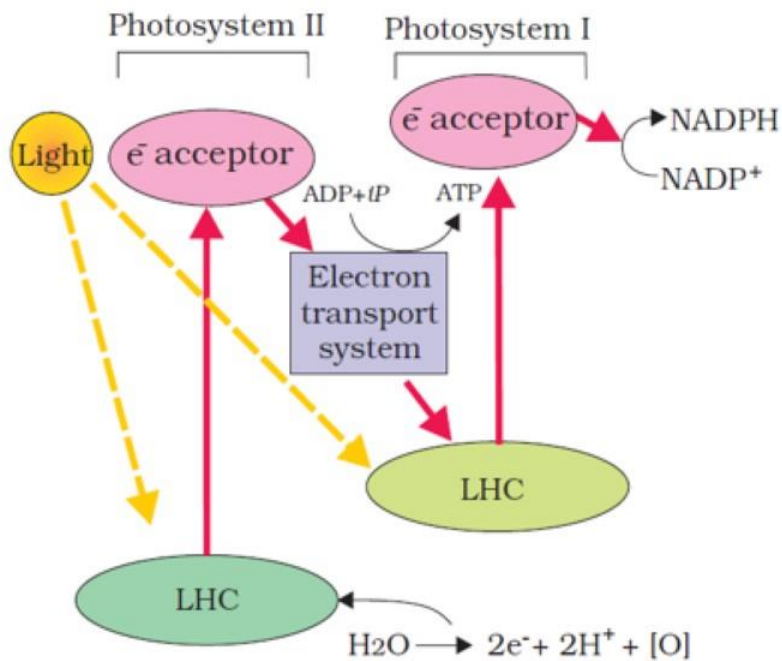


Z scheme of light reaction

The Electron Transport

- When **PS II** absorbs red light of **680 nm** wavelength, **electrons are excited and transferred to an electron acceptor**.
- The electron acceptor passes them to a chain of **electrons transport system** consisting of **cytochromes**.
- This movement of electrons is downhill, in terms of redox potential scale.
- The electrons are transferred to the pigments of **PS I**.

LIGHT REACTION (PHOTOCHEMICAL PHASE)

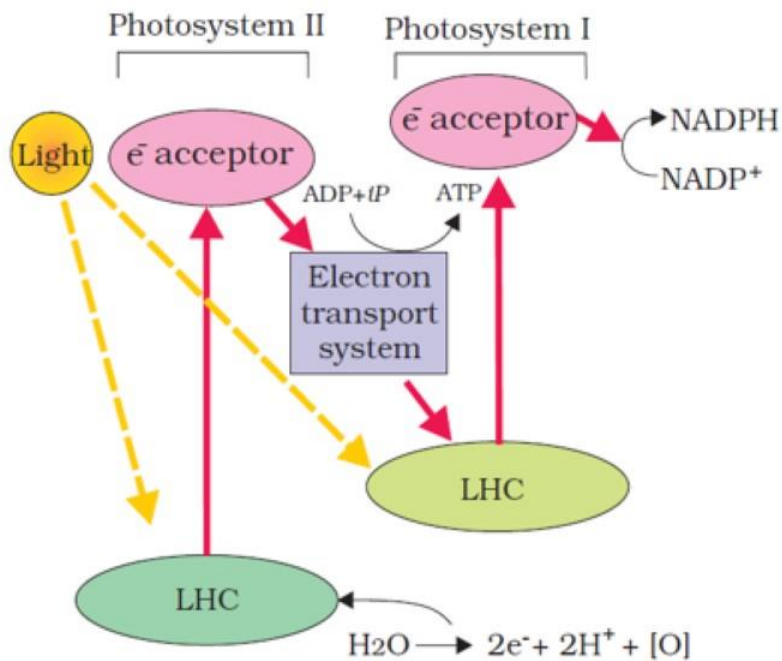


Z scheme of light reaction

The Electron Transport

- Simultaneously, electrons in **PS I** are also excited when they receive **red light of 700 nm** and are transferred to another acceptor molecule having a greater redox potential.
- These electrons are moved downhill to a molecule of $NADP^+$. As a result, **$NADP^+$ is reduced to $NADPH + H^+$** .
- Transfer of electrons from PS II to PS I and finally downhill to $NADP^+$ is called the **Z scheme**, due to its zigzag shape. This shape is formed when all the carriers are placed in a sequence on a redox potential scale.

LIGHT REACTION (PHOTOCHEMICAL PHASE)



Z scheme of light reaction

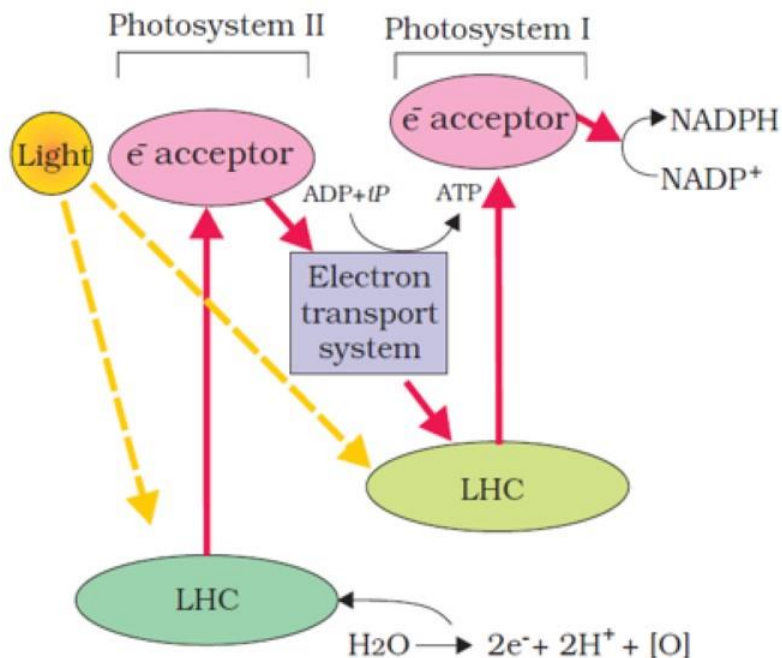
Splitting of Water (Photolysis)

- The **water splitting complex** in PS II is located on the inner side of the thylakoid membrane.
- Water is split into H⁺, [O] and electrons.



- So PS II can supply electrons continuously by replacing electrons from water splitting.
- Thus PS II provides electrons needed to replace those removed from PS I.
- The protons (H⁺) are used to reduce NADP to NADPH.
- O₂ is liberated as by-product of photosynthesis.

LIGHT REACTION (PHOTOCHEMICAL PHASE)

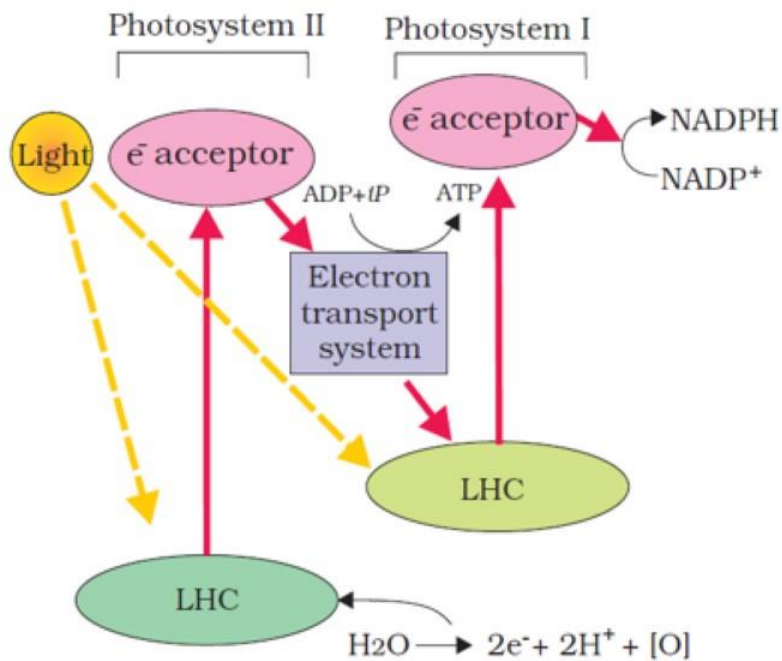


Z scheme of light reaction

Photo-phosphorylation

- The synthesis of ATP by cells (in mitochondria & chloroplasts) is called **phosphorylation**.
- **Photophosphorylation** is the synthesis of ATP from ADP in chloroplasts in presence of light.
- It occurs in 2 ways:
 - **Non- cyclic**
 - **Cyclic**

LIGHT REACTION (PHOTOCHEMICAL PHASE)



Z scheme of light reaction

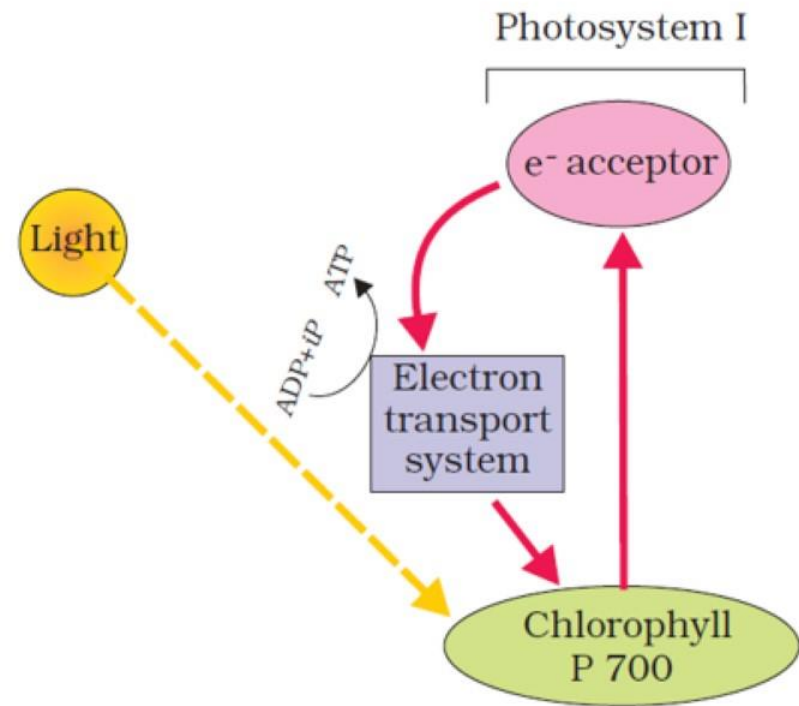
a) Non-cyclic photo-phosphorylation

- It occurs when the two photosystems work in a series, (first **PS II** and then **PS I**) through an electron transport chain as seen in the **Z scheme**.
- Here, **ATP & NADPH + H⁺** are synthesised.
- It is a non-cyclic process because the electrons lost by PS II do not come back to it but pass on to NADP⁺.

LIGHT REACTION (PHOTOCHEMICAL PHASE)

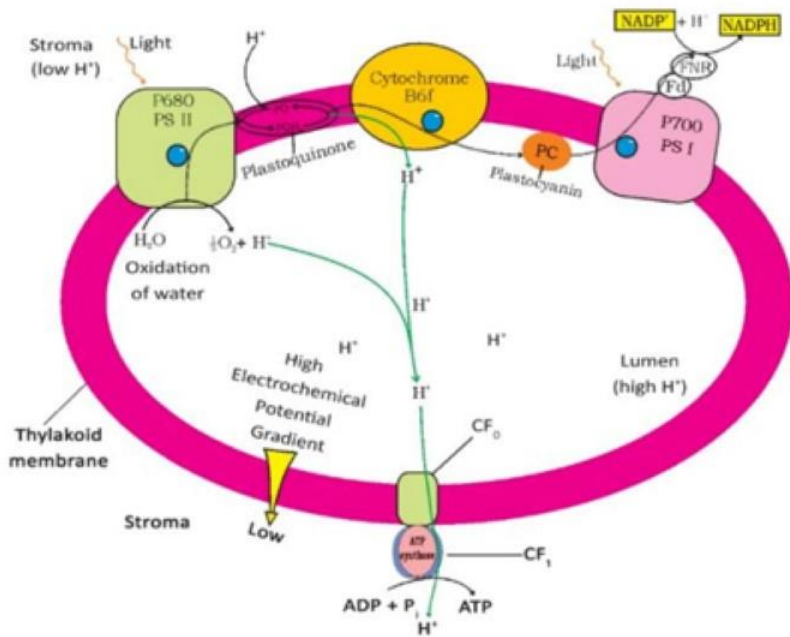
b) Cyclic photo-phosphorylation

- It occurs in **stroma lamellae** when only PS I is functional.
- The electron is circulated within photosystem and ATP synthesis occurs due to cyclic flow of electrons.
- The lamellae of grana have PS I & PS II. The stroma lamellae membranes lack PS II and *NADP reductase*.
- The electron does not pass on to NADP^+ but is cycled back to PS I through electron transport chain.
- Here, **only ATP** is synthesised (no $\text{NADPH} + \text{H}^+$).
- Cyclic photophosphorylation also occurs when only light of wavelengths beyond 680 nm are available.



Cyclic photo-phosphorylation

LIGHT REACTION (PHOTOCHEMICAL PHASE)



ATP synthesis through chemiosmosis

Chemiosmotic Hypothesis

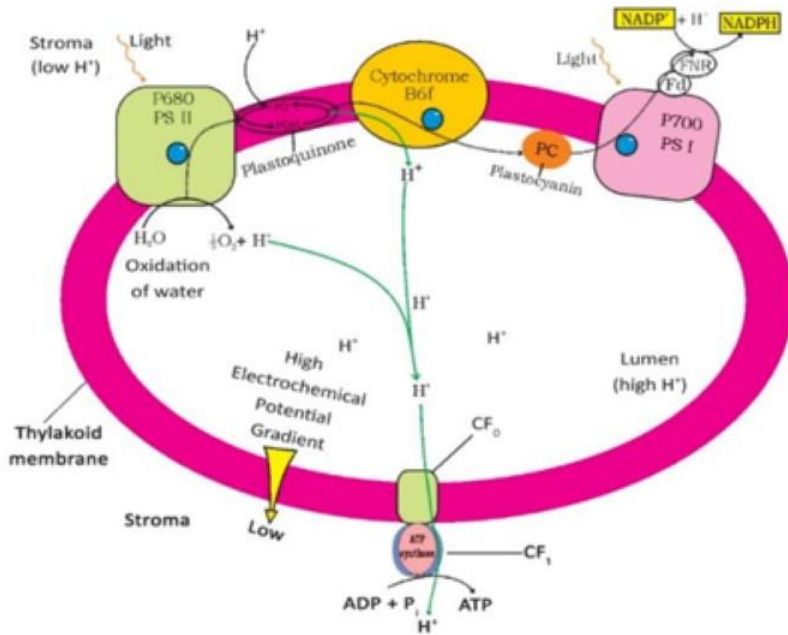
- It explains mechanism of **ATP synthesis in chloroplast**.
- **Chemiosmosis:** Movement of ions across a semipermeable membrane. It occurs in chloroplast and mitochondria.
- Chemiosmosis needs a membrane, a **proton pump**, a proton gradient (across thylakoid membranes) and **ATP synthase**.
- Splitting of water takes place on the inner side of the membrane. So the protons accumulate in the lumen of thylakoids.

LIGHT REACTION (PHOTOCHEMICAL PHASE)

Chemiosmotic Hypothesis

As electrons move through photosystems, protons are transported across the membrane. It is due to the removal of protons from stroma for the following reasons:

1. The primary electron acceptor is located towards the outer side of the membrane and transfers its electron to an H carrier. So this molecule removes a proton from the stroma while transporting an electron. When this molecule passes on its electron to the electron carrier on the inner side of the membrane, proton is released into the lumen of the membrane.



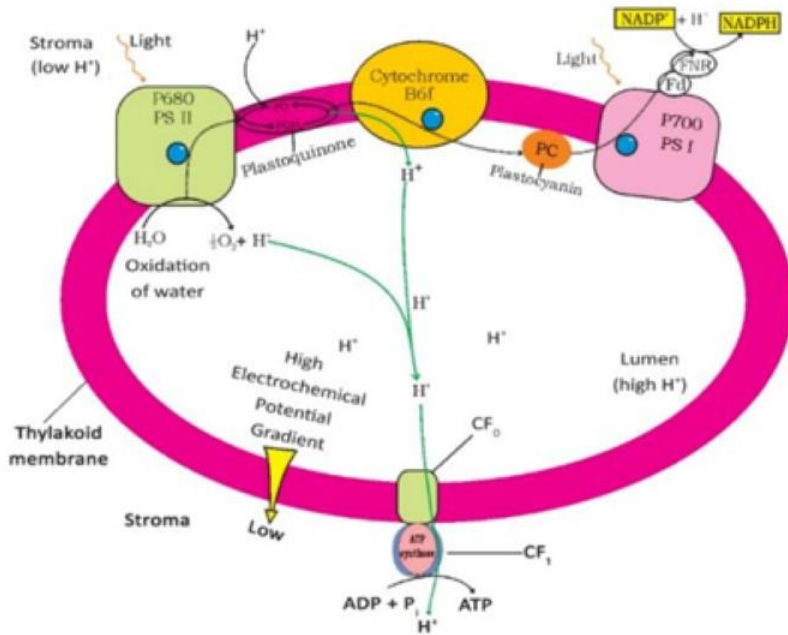
ATP synthesis through chemiosmosis

LIGHT REACTION (PHOTOCHEMICAL PHASE)

Chemiosmotic Hypothesis

As electrons move through photosystems, protons are transported across the membrane. It is due to the removal of protons from stroma for the following reasons:

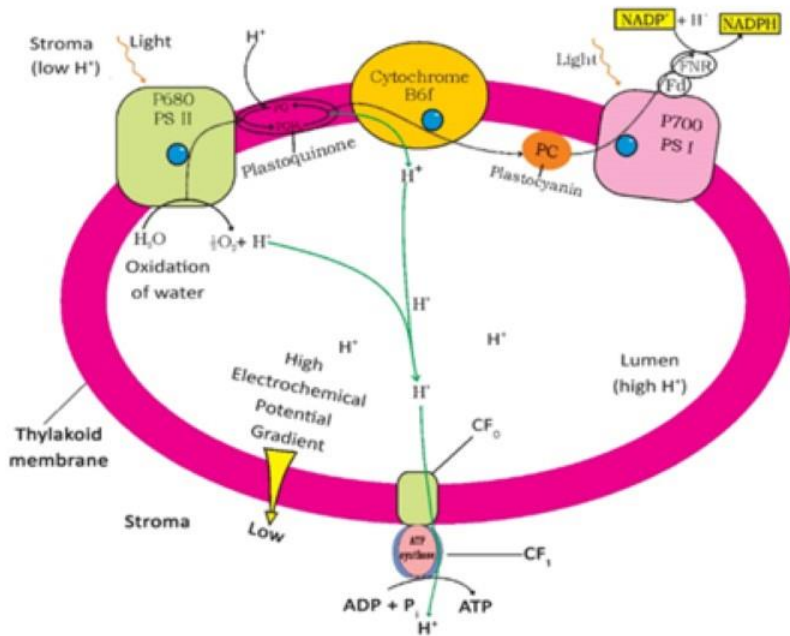
2. The ***NADP reductase*** enzyme is located on stroma side of the membrane. Along with electrons coming from PS I, protons are necessary to reduce NADP^+ . These protons are also removed from stroma.



ATP synthesis through chemiosmosis

LIGHT REACTION (PHOTOCHEMICAL PHASE)

Chemiosmotic Hypothesis



ATP synthesis through chemiosmosis

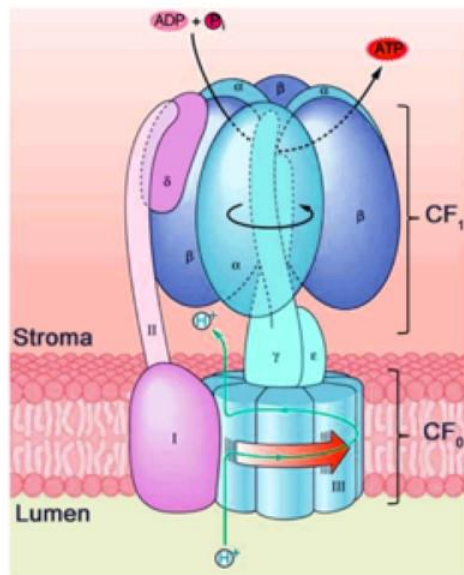
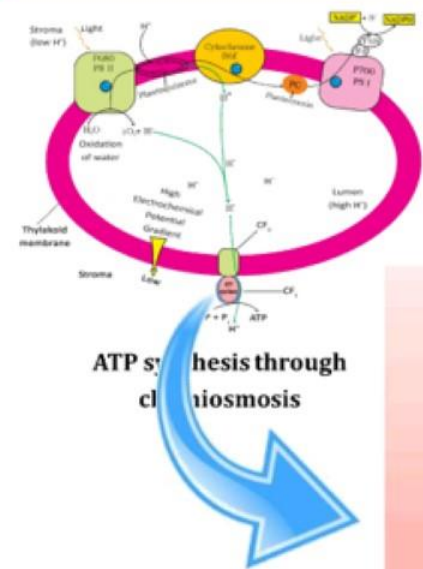
- Hence, protons in stroma are decreased but in lumen, protons are accumulated. It creates a proton gradient across the thylakoid membrane and decrease in pH in the lumen.
- Breakdown of proton gradient leads to synthesis of ATP by **ATP synthase** enzyme.

LIGHT REACTION (PHOTOCHEMICAL PHASE)

Chemiosmotic Hypothesis

ATP synthase consists of two parts:

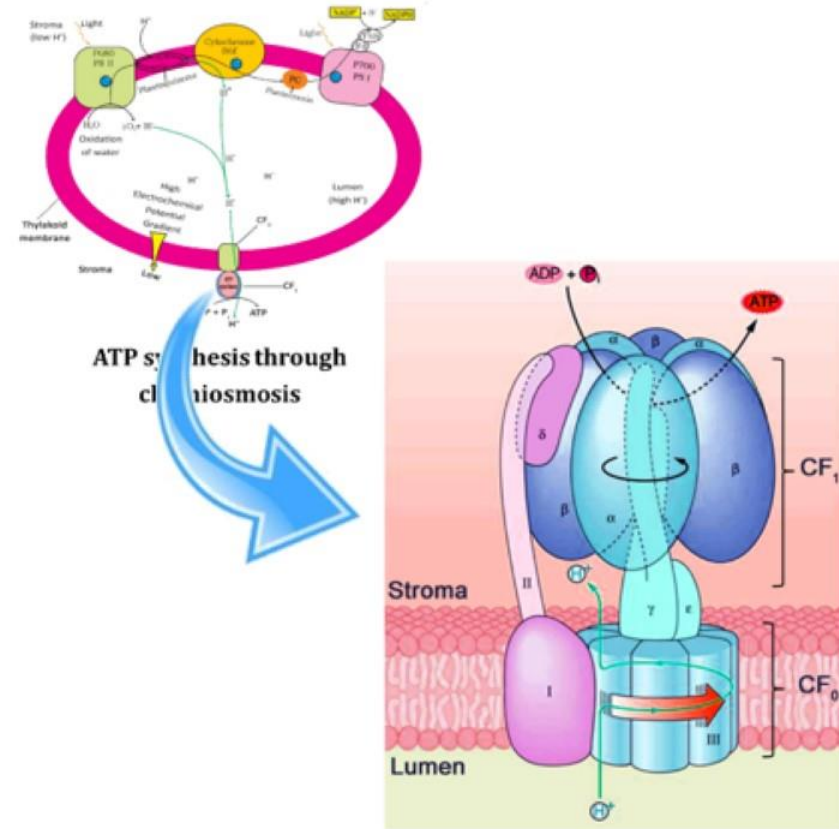
- **CF₀**: It is embedded in the membrane and forms a trans-membrane channel. It carries out facilitated diffusion of protons across the membrane to the stroma. It results in breakdown of proton gradient.
- **CF₁**: It protrudes on the outer surface of the thylakoid membrane. The energy due to breakdown of gradient causes a conformational change in the CF₁ particle. It makes the enzyme to synthesise ATP.



LIGHT REACTION (PHOTOCHEMICAL PHASE)

Chemiosmotic Hypothesis

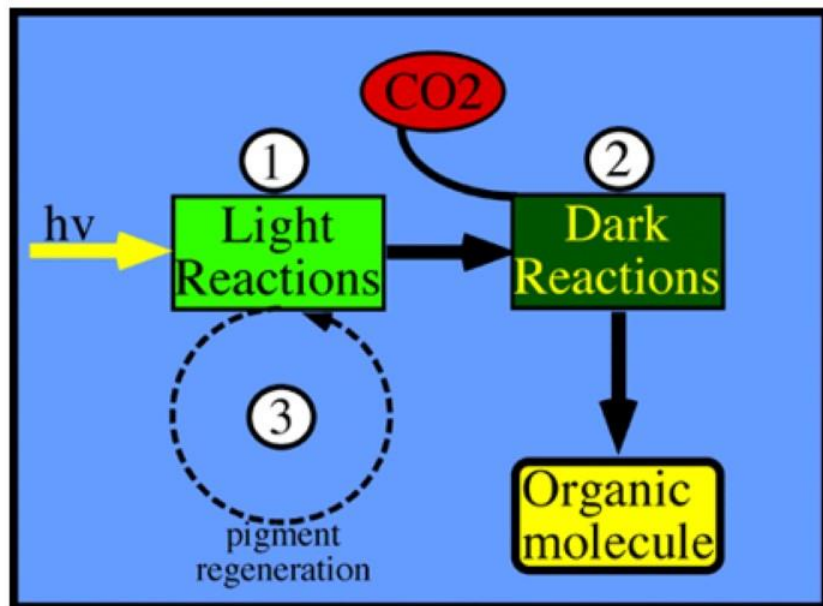
- Energy is used to pump protons across a membrane, to create a gradient or a high concentration of protons within the thylakoid lumen.
- *ATP synthase* has a channel for the diffusion of protons back across the membrane. This releases energy to activate *ATP synthase* that catalyses formation of ATP.



DARK REACTION OR BIOSYNTHETIC PHASE

(USE OF ATP & NADPH)

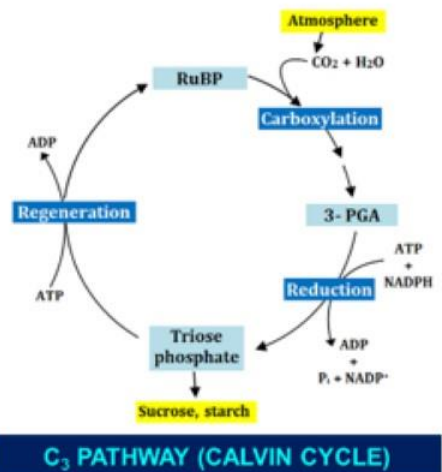
DARK REACTION (BIOSYNTHETIC PHASE)



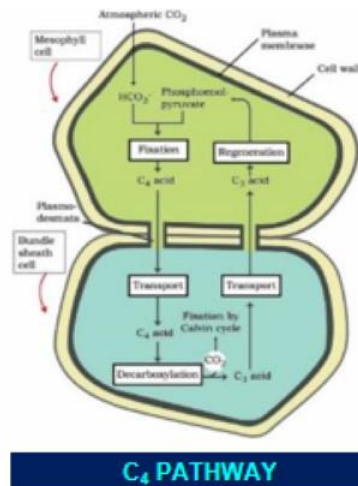
- Products of light reaction are ATP, NADPH & O_2 .
- **Dark reaction** is the use of ATP and NADPH to drive the processes for the synthesis of food (sugars).
- This phase does not directly depend on the light but is dependent on the products of the light reaction.
- It can be verified as follows: Immediately after light becomes unavailable, the biosynthetic process continues for some time, and then stops. If light is available, the synthesis starts again.

DARK REACTION (BIOSYNTHETIC PHASE)

- CO_2 combines with H_2O to form $(\text{CH}_2\text{O})_n$ or sugars.
- CO_2 assimilation during photosynthesis is 2 types:
 - **C_3 pathway:** In this, first product of CO_2 fixation is a C_3 organic acid (**3-phosphoglyceric acid - PGA**). **Melvin Calvin** discovered this using ^{14}C in algal photosynthesis.
 - **C_4 pathway:** In this, first stable product is **oxaloacetic acid (OAA)**, a 4-carbon (C_4) acid.

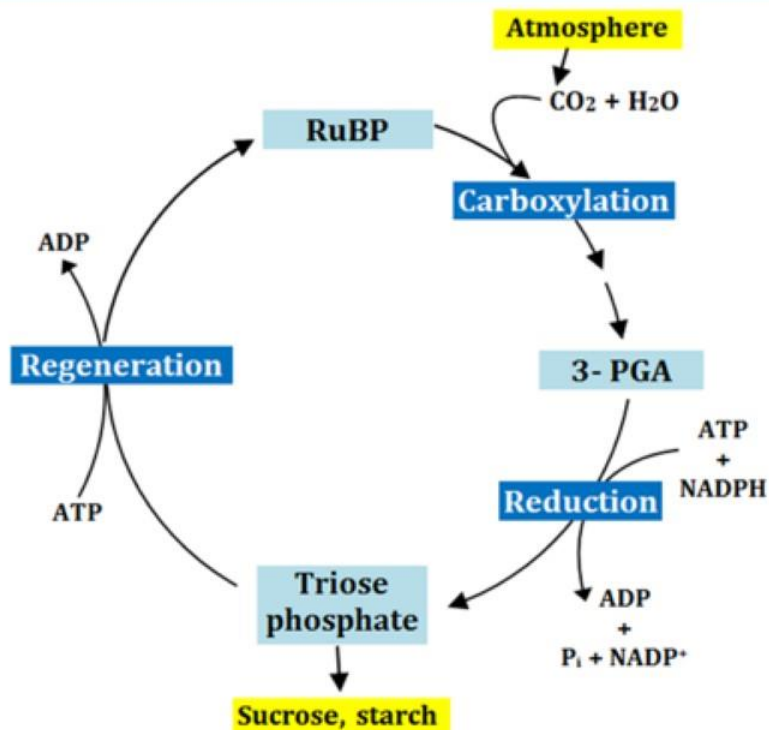


Melvin Calvin



DARK REACTION (BIOSYNTHETIC PHASE)

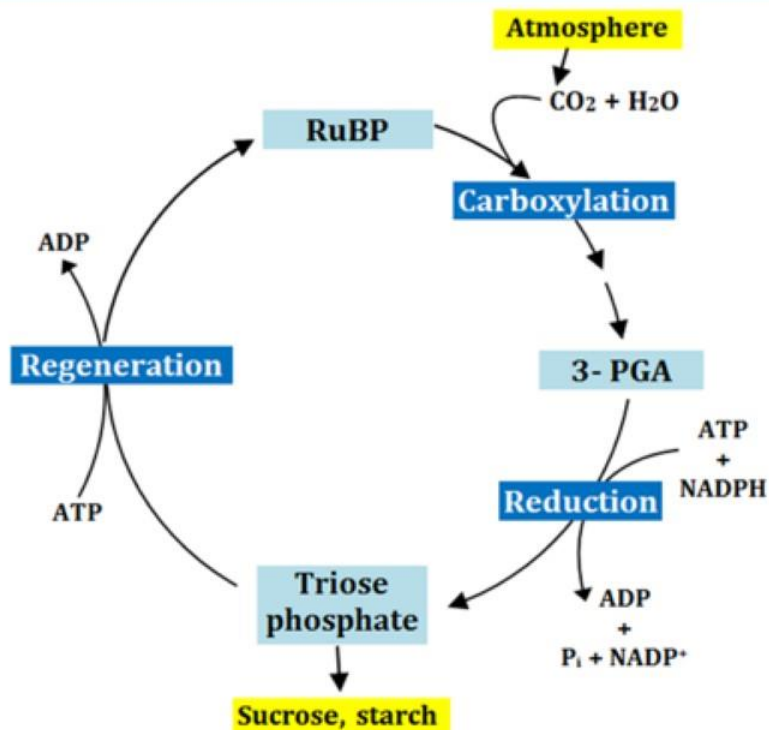
C₃ PATHWAY (CALVIN CYCLE)



C₃ PATHWAY (CALVIN CYCLE)

- It occurs in **all photosynthetic plants** (C₃ or C₄ pathways).
- It has 3 stages:
 1. **Carboxylation**
 2. **Reduction**
 3. **Regeneration**

DARK REACTION (BIOSYNTHETIC PHASE)



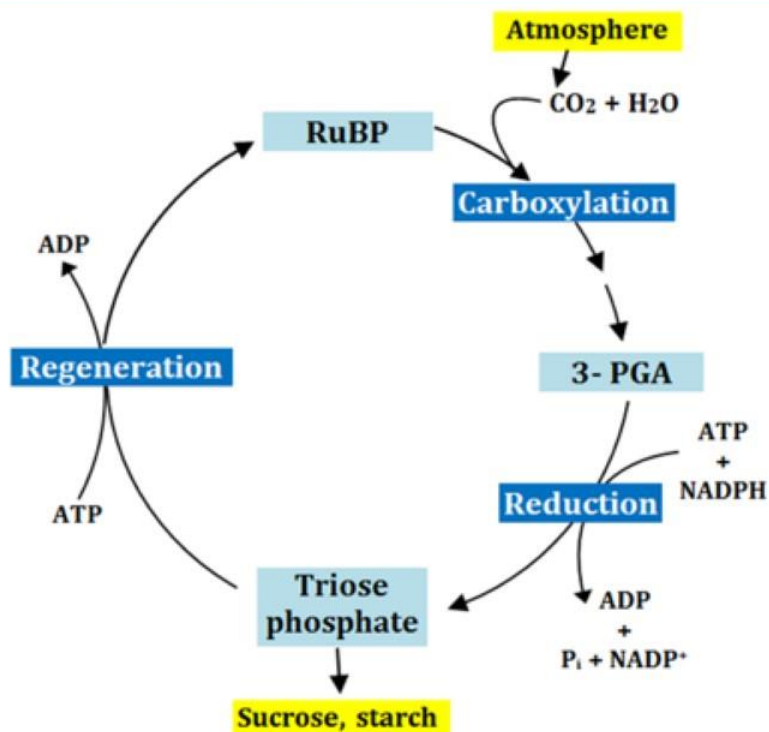
C₃ PATHWAY (CALVIN CYCLE)

C₃ PATHWAY (CALVIN CYCLE)

1. Carboxylation of RuBP

- RuBP (ribulose bisphosphate - a 5-carbon **ketose sugar**) is the primary CO₂ acceptor.
- It is the most crucial step. CO₂ is fixed by RuBP to two 3-PGA in presence of the enzyme ***RuBP carboxylase***.
- Since this enzyme also has an oxygenation activity it is called ***RuBP carboxylase-oxygenase (RuBisCO)***.
- ***RuBisCO*** is the most abundant enzyme in the world.

DARK REACTION (BIOSYNTHETIC PHASE)



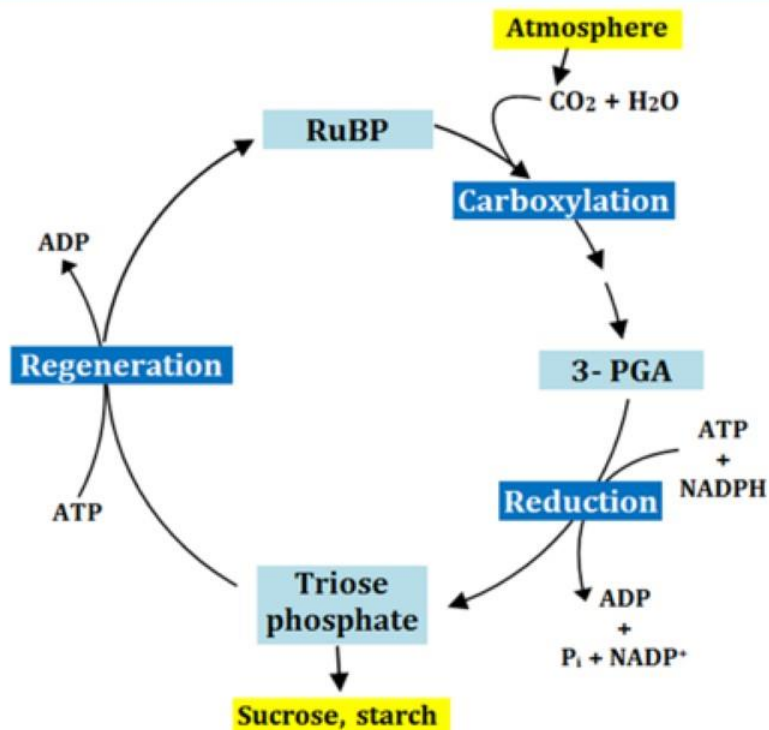
C₃ PATHWAY (CALVIN CYCLE)

2. Reduction

- It is a series of reactions leading to the **glucose formation**.
- Here, **2 ATP molecules** for phosphorylation and **two NADPH** for reduction per CO₂ molecule are used.
- Fixation of 6 CO₂ molecules and 6 turns of the cycle are needed to remove one glucose molecule from the pathway.

C₃ PATHWAY (CALVIN CYCLE)

DARK REACTION (BIOSYNTHETIC PHASE)



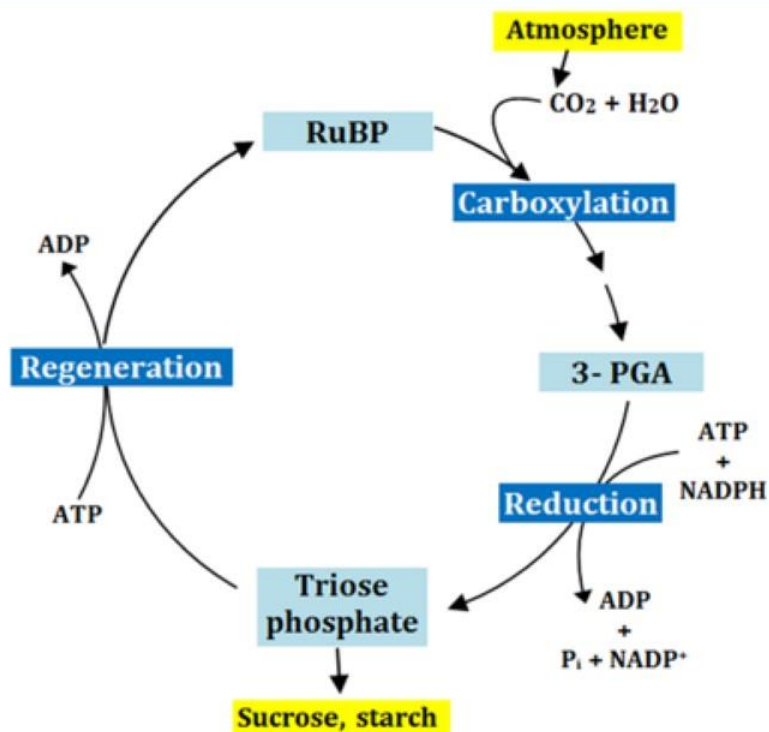
C₃ PATHWAY (CALVIN CYCLE)

3. Regeneration of RuBP

- It is crucial for continuation of the cycle.
- It requires one ATP for phosphorylation to form RuBP.
- Hence for every CO₂ molecule, 3 ATP molecules and 2 NADPH are required.
- It is probably to meet this difference in number of ATP and NADPH used in the dark reaction that the cyclic phosphorylation takes place.
- To make one glucose molecule, 6 turns of the cycle are needed.

C₃ PATHWAY (CALVIN CYCLE)

DARK REACTION (BIOSYNTHETIC PHASE)



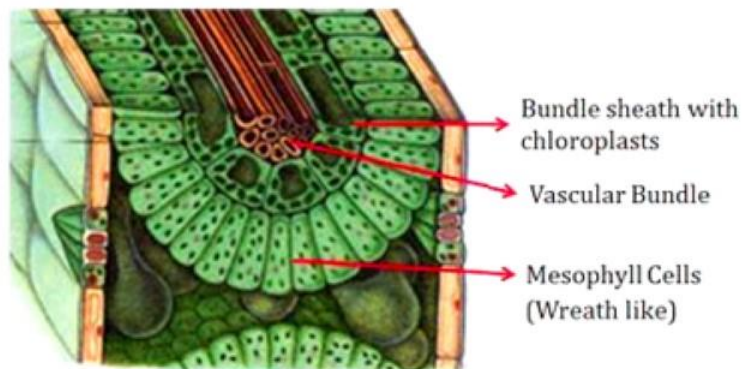
C₃ PATHWAY (CALVIN CYCLE)

What does go in and come out of the Calvin cycle?

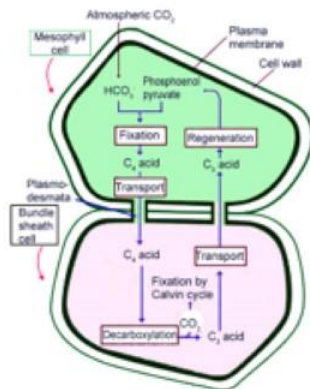
In	Out
6 CO ₂	1 glucose
18 ATP	18 ADP
12 NADPH	12 NADP

C₃ PATHWAY (CALVIN CYCLE)

DARK REACTION (BIOSYNTHETIC PHASE)



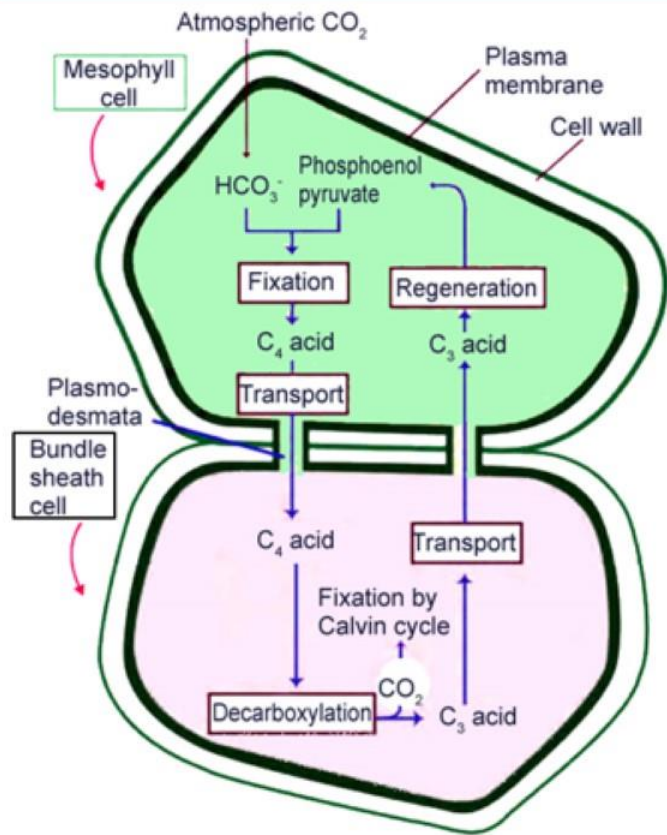
Kranz Anatomy



C4 PATHWAY (HATCH & SLACK PATHWAY)

- It is present in plants adapted to **dry tropical regions**.
- They also use C₃ pathway as main biosynthetic pathway.
- The large cells around the vascular bundles of the C₄ plants are called **bundle sheath cells**. Such anatomy is called '**Kranz**' anatomy.
- The bundle sheath cells may form several layers around the vascular bundles.
- They have **large number of chloroplasts, thick walls** impervious to gas exchange and **no intercellular spaces**.

DARK REACTION (BIOSYNTHETIC PHASE)



C4 PATHWAY (HATCH & SLACK PATHWAY)

Steps of Hatch and Slack Pathway

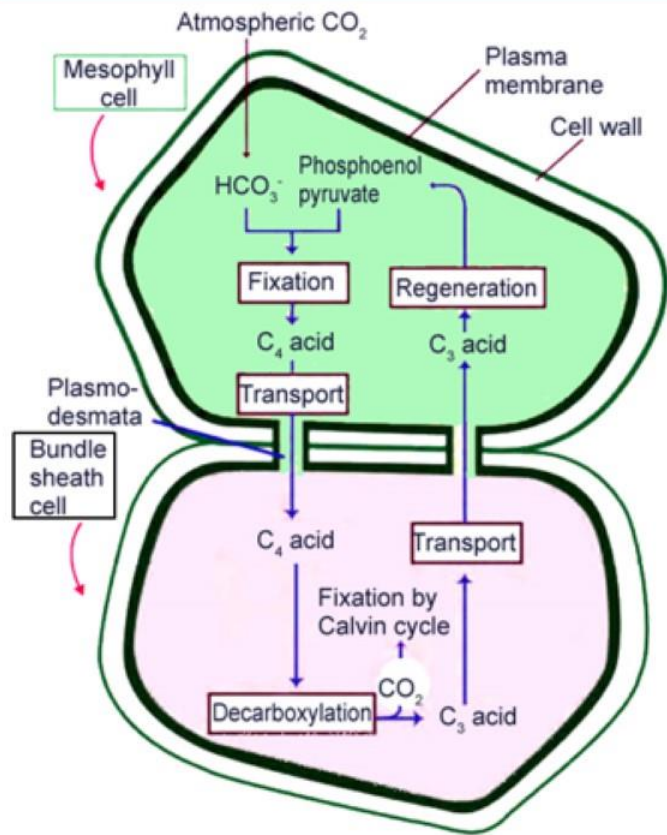
- ➔ Primary CO₂ acceptor is **phosphoenol pyruvate (PEP)**. It is a 3-carbon molecule seen in mesophyll cells. The enzyme for this fixation is *PEP carboxylase (PEPcase)*.
- ➔ The mesophyll cells **lack RuBisCO** enzyme.
- ➔ The C₄ acid **OAA** is formed in mesophyll cells.
- ➔ It then forms other 4-carbon acids like malic acid or aspartic acid. They are transported to bundle sheath cells.

DARK REACTION (BIOSYNTHETIC PHASE)

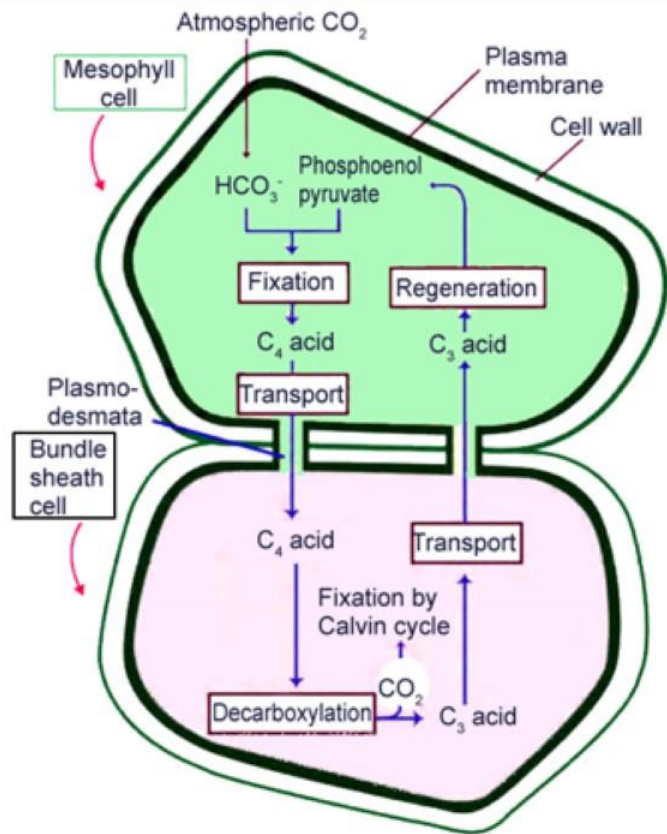
C4 PATHWAY (HATCH & SLACK PATHWAY)

Steps of Hatch and Slack Pathway

- ➔ In the bundle sheath cells, C_4 acids are broken down to release CO_2 & a C_3 molecule.
- ➔ The C_3 molecule is transported back to mesophyll where it is converted to PEP again.
- ➔ The released CO_2 enters the C_3 pathway.
- ➔ Bundle sheath cells are rich in ***RuBisCO***, but lack *PEPcase*. Thus C_3 pathway is common to C_3 & C_4 plants.



DARK REACTION (BIOSYNTHETIC PHASE)

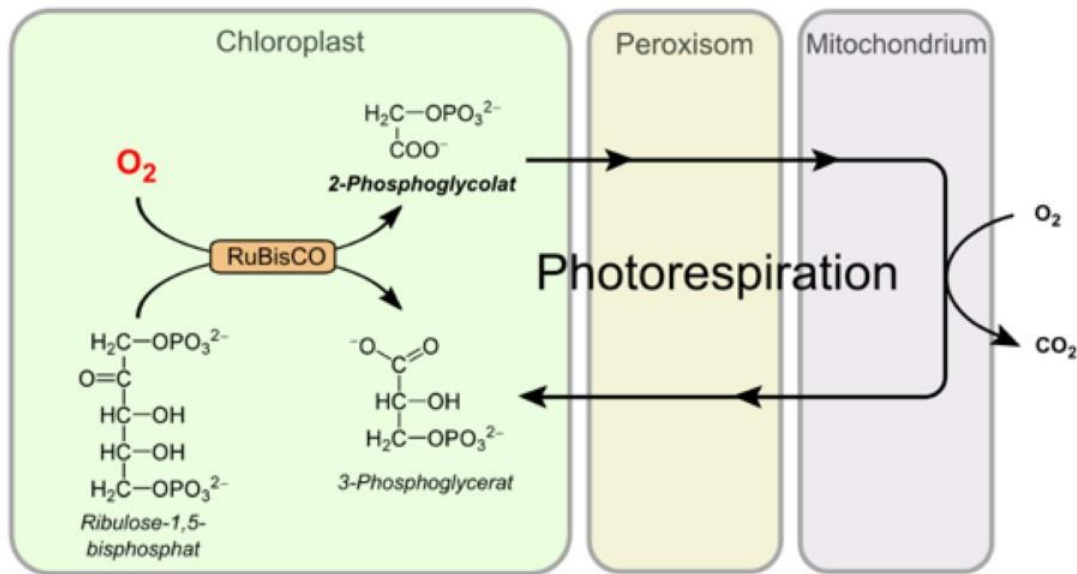


C₄ PATHWAY (HATCH & SLACK PATHWAY)

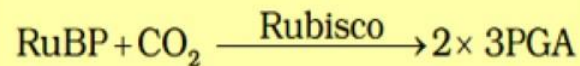
C₄ plants are special because:

- They have a special type of leaf anatomy (**Kranz**).
- They tolerate **higher temperatures**.
- They show a response to **high light intensities**.
- They **lack photorespiration**.
- They have **greater productivity** of biomass.

PHOTORESPIRATION

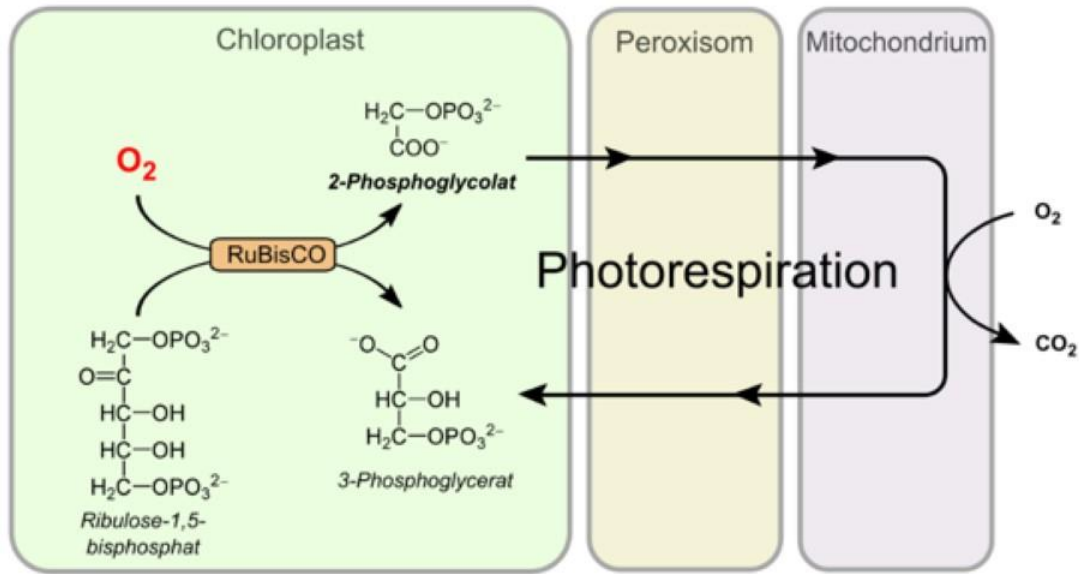


- In Calvin pathway, **RuBP** combines with **CO₂**.



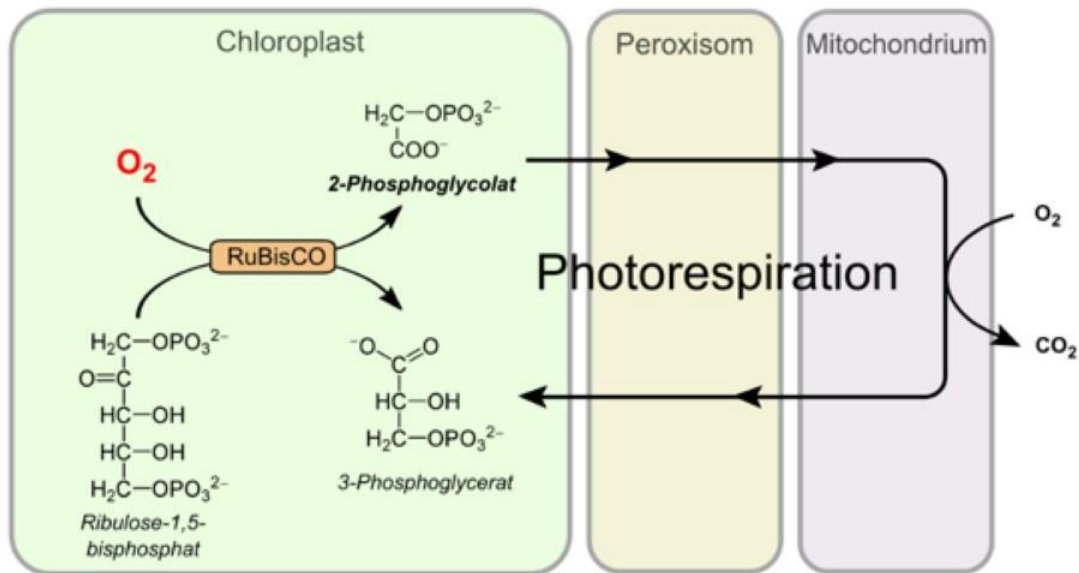
- Active site of **RuBisCO** can bind to **CO₂** and **O₂** – hence the name.
- RuBisCO** has greater affinity for **CO₂** than for **O₂**. This binding is competitive. Relative concentration of **O₂** and **CO₂** determines which one will bind to the enzyme.

PHOTORESPIRATION



- In C_3 plants some O_2 bind to *RuBisCO*. Hence CO_2 fixation is decreased. Here RuBP binds with O_2 to form one molecule of **phosphoglycerate** and **phosphoglycolate**. This pathway is called **photorespiration**.
- In this pathway, there is no synthesis of sugars, ATP and NADPH. Hence **photorespiration is a wasteful process**. Rather it causes the release of CO_2 by using ATP.

PHOTORESPIRATION



- In **C₄ plants**, photorespiration does not occur because they can increase CO_2 concentration at the enzyme site. This takes place when C₄ acid from the mesophyll is broken down in the bundle cells to release CO_2 . This minimises the oxygenase activity of *RuBisCO*.
- Due to the lack photorespiration, productivity and yields are better in C₄ plants. In addition these plants show tolerance to higher temperatures.

DIFFERENCES BETWEEN C₃ AND C₄ PLANTS

C ₃ plants	C ₄ plants
1. Photosynthesis occurs in mesophyll cells.	In mesophyll and bundle sheath cells.
2. Kranz anatomy is absent.	Present.
3. RuBP is the primary CO ₂ acceptor.	PEP is the primary CO ₂ acceptor.
4. 3-PGA, a 3-C compound is the first stable product.	OAA, a 4-C compound is the first stable product.
5. Chloroplasts are of only one type (granal).	Chloroplasts are dimorphic (granal in mesophyll and agranal in bundle sheath).
6. Photorespiratory loss is high.	Photorespiration is absent or negligible.
7. High CO ₂ compensation point (25-100 ml. CO ₂ l ⁻¹).	Low CO ₂ compensation point (0-10 ml. CO ₂ l ⁻¹).
8. Optimum temperature for photosynthesis is about 25°C.	About 35°C - 45°C .
9. Photosynthetically less efficient and productivity low. E.g. Rice, wheat, bean, potato.	Photosynthetically more efficient and productivity high. E.g. Maize, sugarcane, amaranth, sorghum.

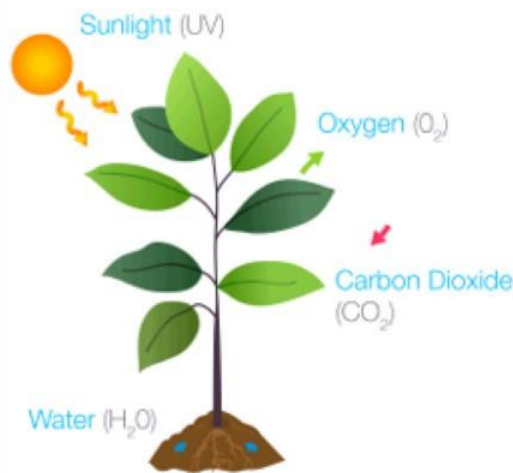
FACTORS AFFECTING PHOTOSYNTHESIS



FACTORS AFFECTING PHOTOSYNTHESIS

Internal (plant) factors

- Number, size, age and orientation of leaves, mesophyll cells and chloroplasts.
- Internal CO_2 concentration.
- Amount of chlorophyll.

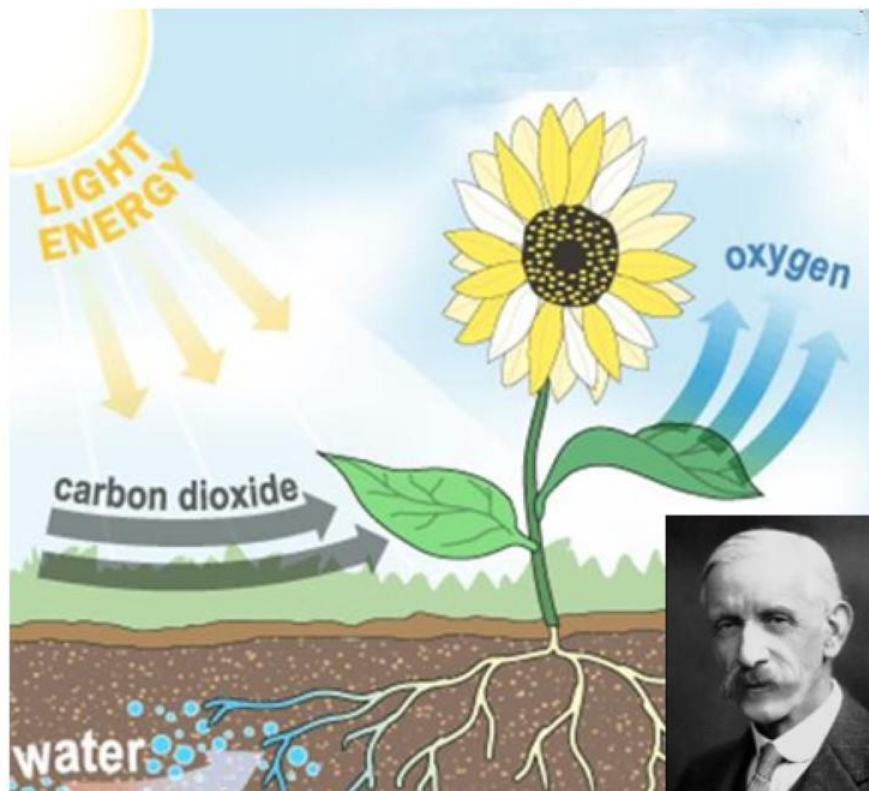


External factors

- Sunlight
- Temperature
- CO_2 concentration
- Water

Plant factors are dependent on the genetic predisposition and the growth of the plant.

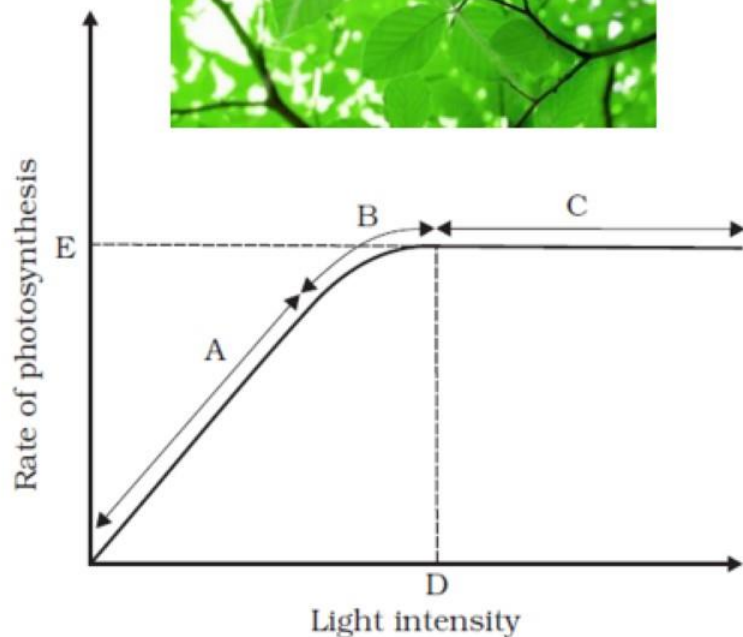
FACTORS AFFECTING PHOTOSYNTHESIS



Blackman's Law of Limiting Factors (1905)

- "If a biochemical process is affected by more than one factor, its rate is determined by the factor nearest to its minimal value: it is the factor which directly affects the process if its quantity is changed."*
- E.g. a plant with green leaf, optimal light & CO_2 may not photosynthesize in very low temperature. If optimal temperature is given, it will start photosynthesis.

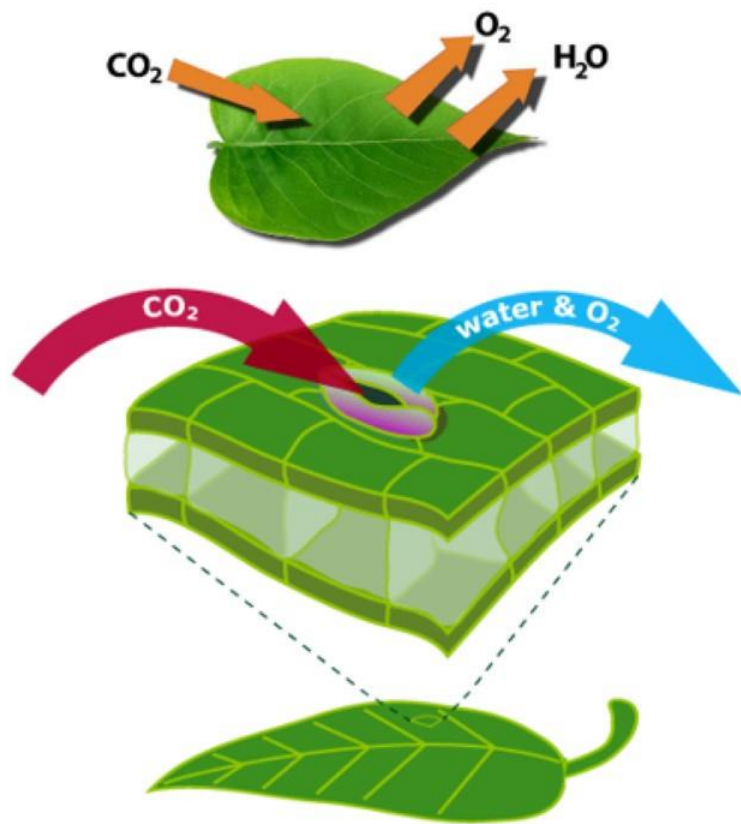
FACTORS AFFECTING PHOTOSYNTHESIS



LIGHT

- **Light quality, light intensity and duration of exposure to light** influence photosynthesis.
- There is a linear relationship between incident light and CO_2 fixation rates at low light intensities.
- At higher light intensities, the rate does not further increase because other factors become limiting.
- Light saturation occurs at **10%** of the full sunlight. Hence, except for plants in shade or in dense forests, light is rarely a limiting factor in nature.
- High increase in incident light breaks down chlorophyll. It decreases photosynthesis.

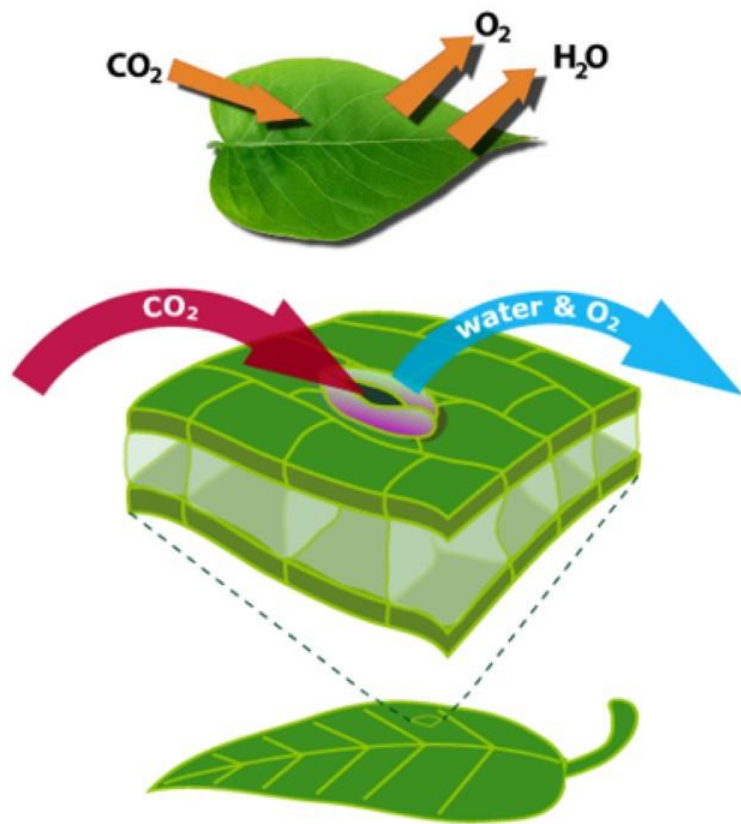
FACTORS AFFECTING PHOTOSYNTHESIS



CARBON DIOXIDE CONCENTRATION

- **Major limiting factor** for photosynthesis.
- CO₂ concentration is very low in the atmosphere (**0.03- 0.04%**).
- Increase up to **0.05%** cause increase in CO₂ fixation rates. Beyond this level, it becomes damaging over longer periods.
- At low light conditions C₃ and C₄ plants do not respond to high CO₂ conditions. At high light intensities, they show increased rate of photosynthesis.

FACTORS AFFECTING PHOTOSYNTHESIS



CARBON DIOXIDE CONCENTRATION

- C_4 plants show saturation at about 360 mL^{-1} .
- C_3 plants respond to increased CO_2 concentration and saturation is seen only beyond 450 mL^{-1} . Thus, current availability of CO_2 levels is limiting to the C_3 plants.
- Due to response to higher CO_2 concentration, C_3 plants show increased photosynthesis and higher productivity. This fact is used for some greenhouse crops (tomatoes, bell pepper etc.). They are grown in CO_2 enriched atmosphere that leads to higher yields.

FACTORS AFFECTING PHOTOSYNTHESIS

TEMPERATURE

- **Dark reactions**, being enzymatic, are temperature controlled. Influence of temperature on Light reactions is very less.
- The **C₄ plants** respond to higher temperatures and show higher rate of photosynthesis.
- **C₃ plants** have a much lower temperature optimum.
- The temperature optimum of plants also depends on their habitat. Tropical plants have a higher temperature optimum than the plants adapted to temperate climates.

FACTORS AFFECTING PHOTOSYNTHESIS

WATER



- **Water stress** closes the **stomata** hence reduce the CO_2 availability.
- Water stress also **wilts leaves**, thus reduce the surface area of the leaves and their metabolic activity.