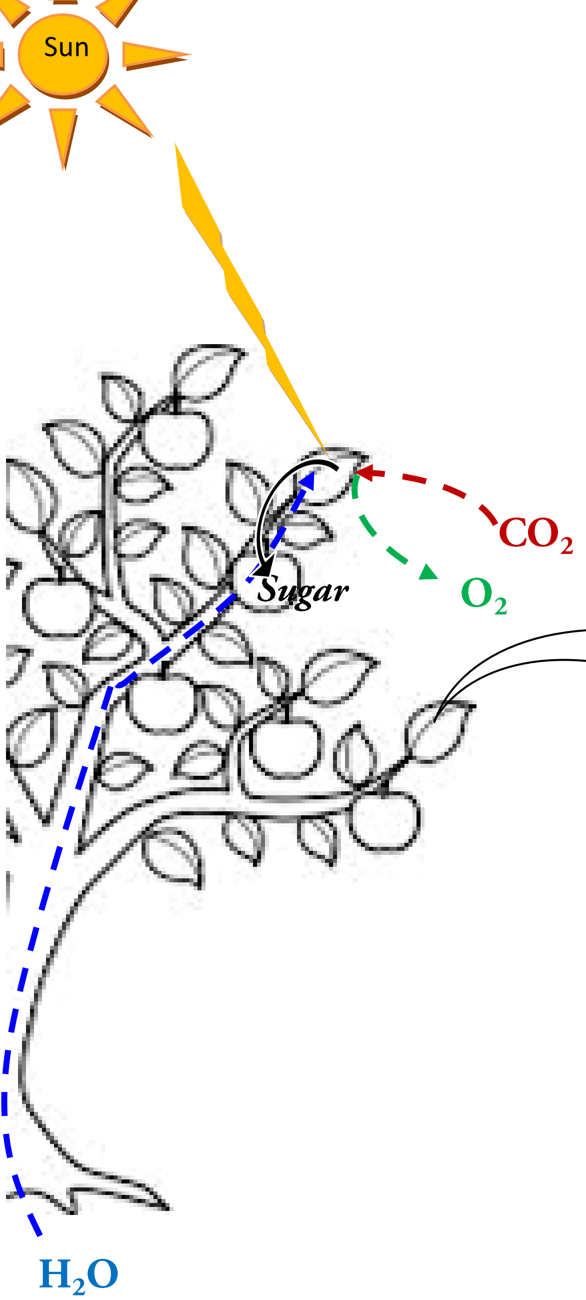


Plant Cell

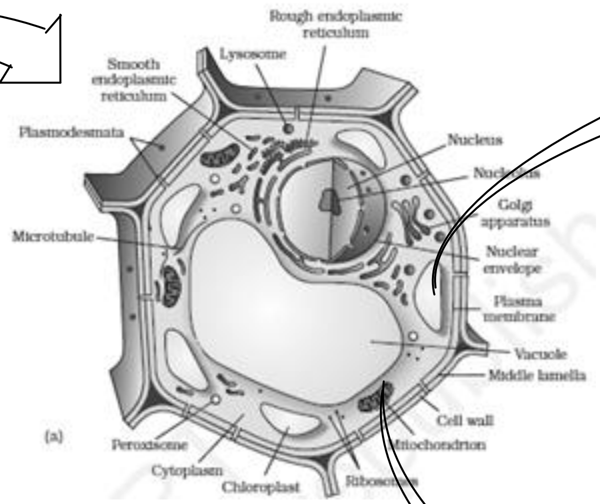
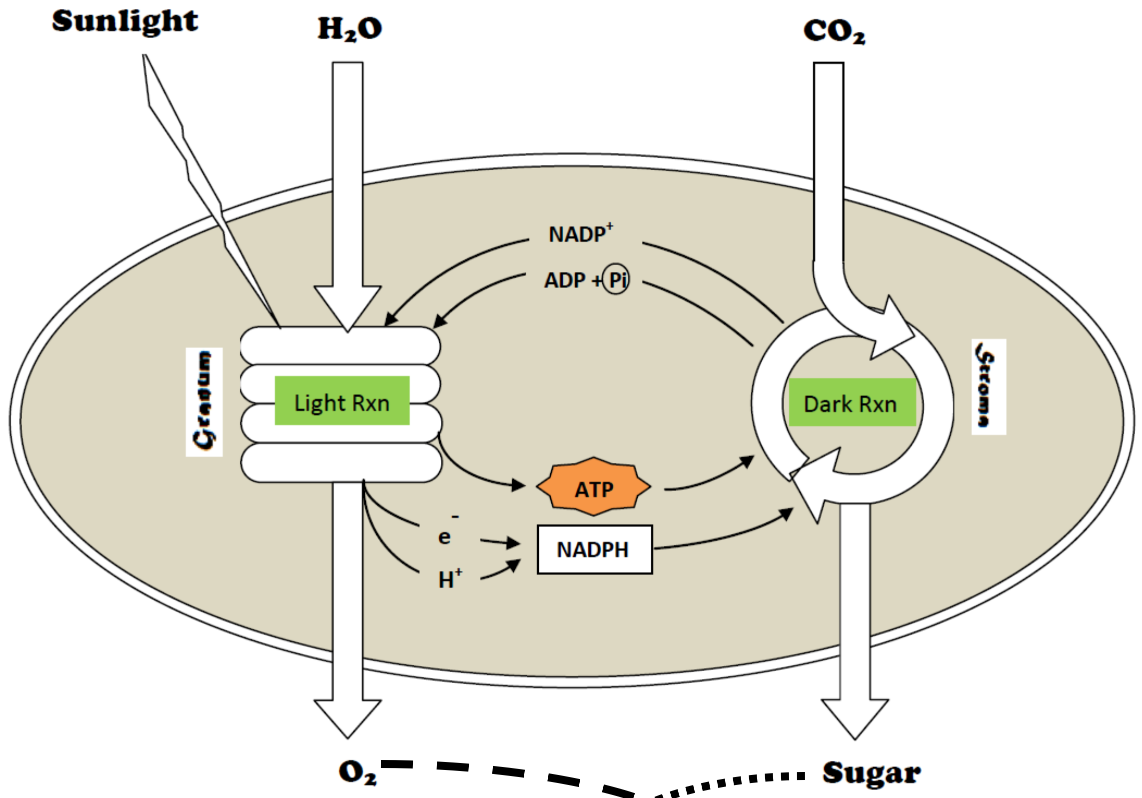
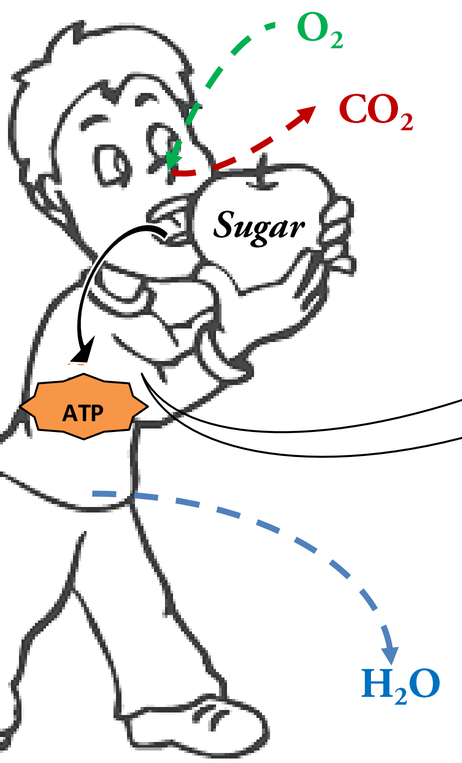
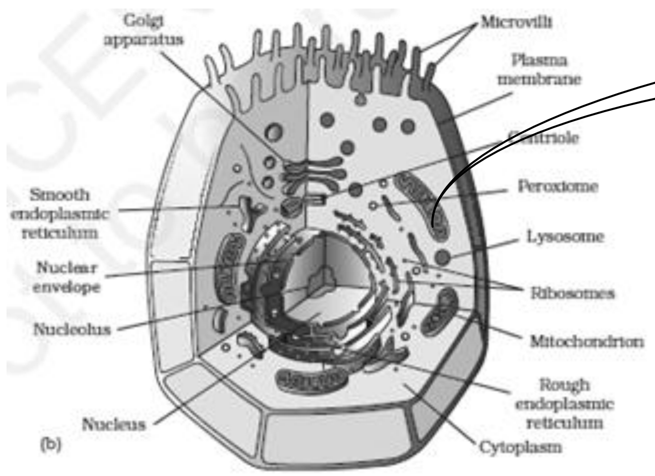


PHOTO-SYNTHESIS

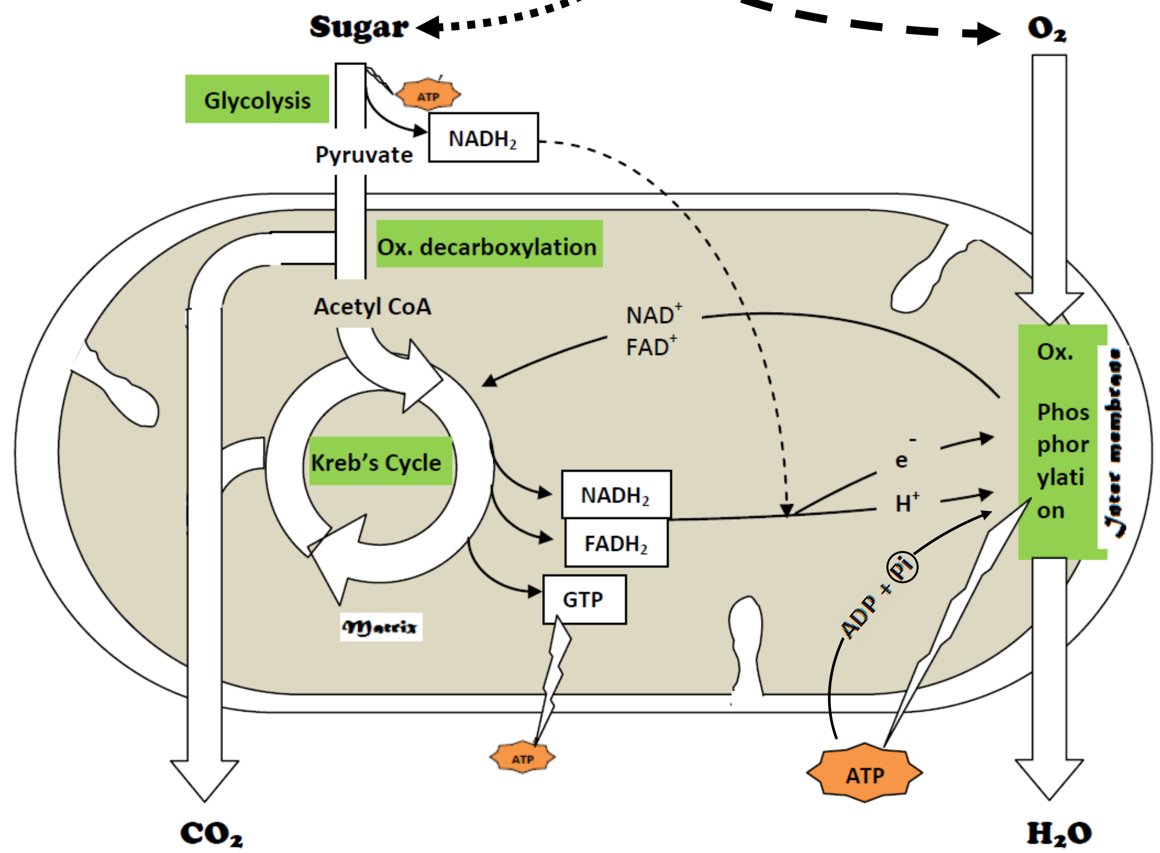




Animal Cell



CELL-RESPIRATION



Concept by,
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BTNY-MM: XI

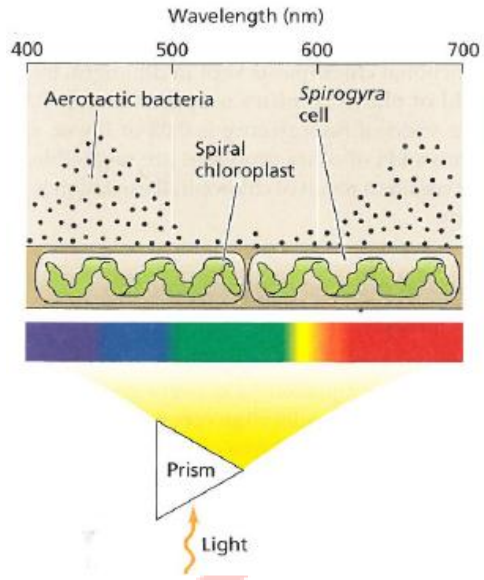
13. PHOTOSYNTHESIS

Photosynthesis is a physico-chemical process by which plants, algae and photosynthetic bacteria use light energy to synthesize organic compounds. It is the basis of life on earth.

Importance of Photosynthesis

- 1^0 source of all food on earth.
- Releases O_2 into the atmosphere.

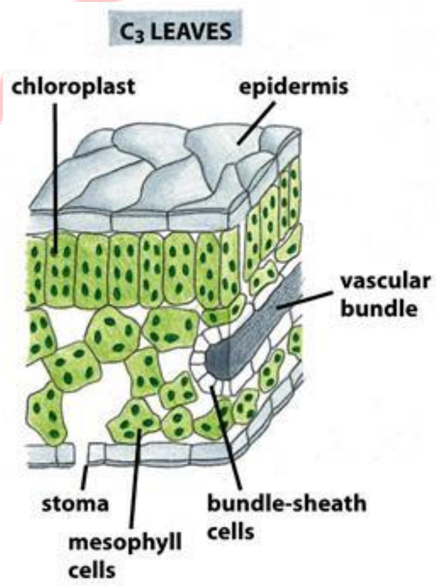
Historical Perspective



1770: **Joseph Priestley** showed the essential role of air in the growth of green plants.
1779: **Jan Ingenhousz** showed the release of O_2 by plants was possible only in sunlight and only by the green parts.
1854: **Julius von Sachs** provided evidence for production of glucose (stored as starch). Also showed that the green substance in plants (chlorophyll) is located in chloroplasts.
1885: **T.W Engelmann** described the effect of different wavelength of light on photosynthesis (using *Cladophora*) and plotted the first action spectrum of photosynthesis.
1905: **Blackman** formulated "*Law of Limiting Factors*".
1924: **Cornelius van Niel** showed that some bacteria use H_2S (as H-donor) instead of H_2O in photosynthesis in green plants (H from an oxidizable compound reduces CO_2 to form sugar). Hence he inferred that the O_2 evolved by the green plant comes from H_2O, not from CO_2. He gave a simplified chemical equation of photosynthesis-

$$6CO_2 + 12H_2O \xrightarrow{\text{Light}} C_6H_{12}O_6 + 6H_2O + 6O_2$$

1954: **Melvin Calvin** traced the path of carbon fixation in photosynthesis
1965: **Hatch** and **Slack** reported the C_4 pathway of CO_2 fixation.



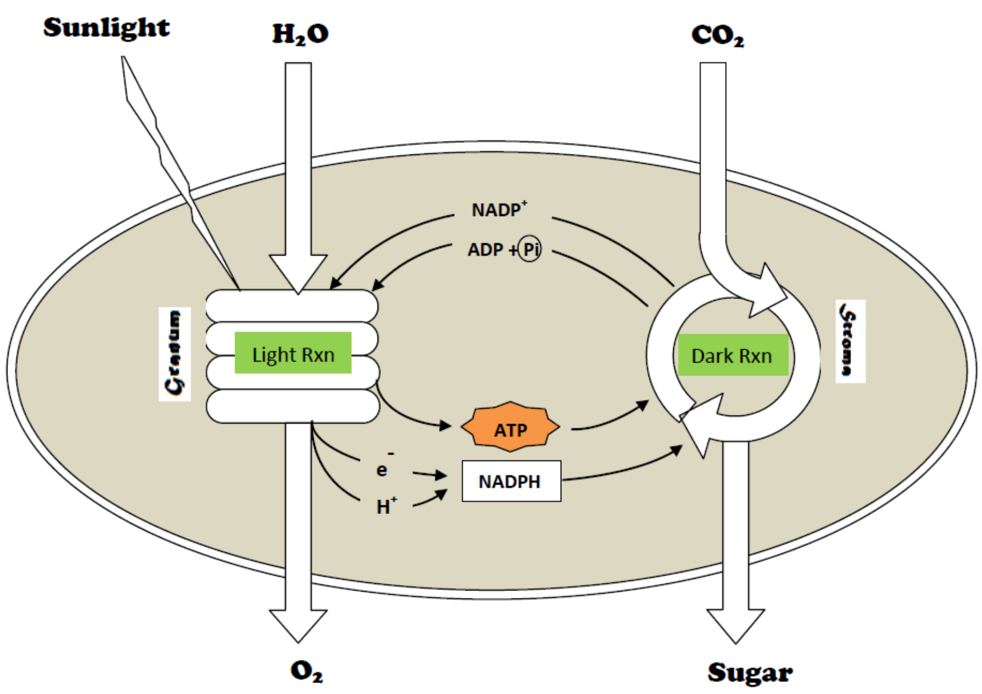
CHLOROPLAST- Site of Photosynthesis:-

Photosynthesis takes place in the green parts of the plants. The most active photosynthetic tissue in higher plants is the mesophyll of leaf. Walls of mesophyll cell have 10-100 membrane-bound **chloroplasts**, which is filled with a fluid called the ***stroma***. The stroma contains stacks of membranous disks called ***grana***.

Mechanism of Photosynthesis:-

The process of photosynthesis can be divided into 2-

I. ***Light reactions*** or the ***'Photochemical' phase*** include light absorption, water splitting, O_2 release, and the formation of ATP and NADPH (energy-storage molecules). Take place in *grana*.
II. ***Dark reactions*** or the ***'Biosynthetic' phase*** uses ATP and NADPH to reduce CO_2 which lead to the synthesis of $(CH_2O)_n$ or **sugars**. Take place in *stroma*.



I. *Light reactions / Photochemical phase*

SET-UP OF LIGHT REACTION-

4 major complexes are involved in the light reaction. They are embedded in the ***thylakoid*** (each sac of grana) membranes. They are-

(i) Photosystem II
(ii) Electron Transport System (ETS)
(iii) Photosystem I
(iv) ATP synthase.

Photosystems (I & II) is composed of Light Harvesting Complex (LHC- responsible for trapping light) and an electron acceptor. The LHC are made up of 200-300 of pigment molecules bound to proteins.

➔ 4 pigments seen in leaves are -

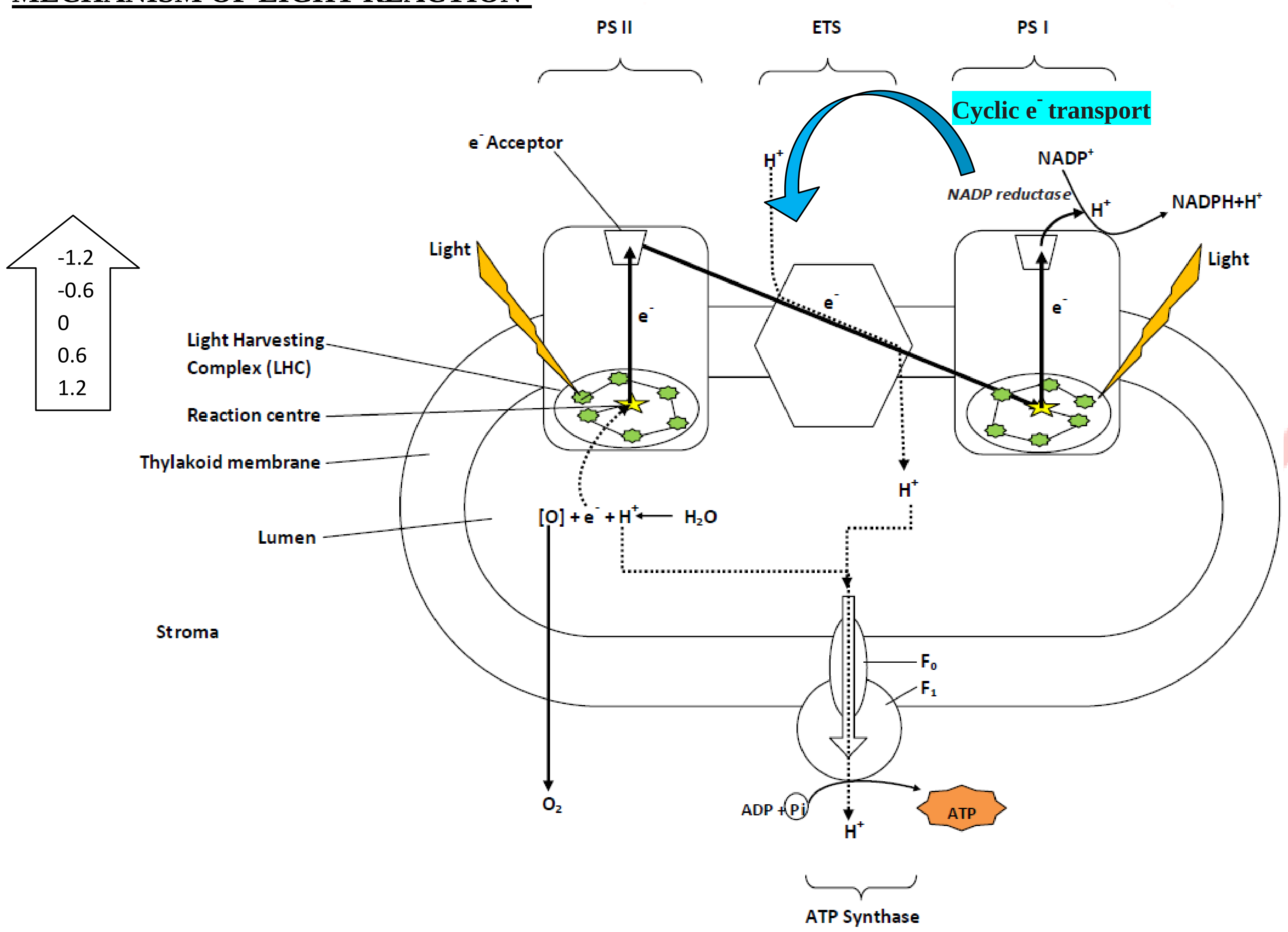
Pigments	Role
• **Chlorophyll *a*** (bright or blue green)	➢ Act as **reaction centre** of LHC.
• **Chlorophyll *b*** (yellow green)	***Accessory pigments***- forming a **light harvesting system** (or **antennae**). ✓ Absorb light and transfer the energy to chlorophyll *a*. ✓ Protect chlorophyll *a* from photo-oxidation
• **Xanthophylls** (yellow)	
• **Carotenoids** (yellow-orange)	

➢ In PS I the reaction centre chlorophyll *a* has an absorption peak at 700 nm, hence is called $\mathbf{P_{700}}$.
In PS II it has absorption maxima at 680 nm, and is called $\mathbf{P_{680}}$.

Differences between PS I & PS II

PS I	PS II
1. Reaction centre of PS I absorb at or below **700nm** wave length of light.	1. At or below **680nm.**
2. This system is **not directly involved** with photo oxidation of water (to replace e^- those removed from PS I to reduce NADP) & evolution of molecular O_2.	2. **Involved**
3. PS I is **involved both** in cyclic & non-cyclic e^- transport.	3. PS II involved **only in non-cyclic** e^- transport.

MECHANISM OF LIGHT REACTION-



(Step-1) When PS II absorbs 680 nm wavelength of red light, e^- are excited and picked by an e^- acceptor.
The e^- that were moved from the reaction centre is replaced by e^- available due to splitting of water in the lumen. The H^+ and O_2 are formed. O_2 diffuses out.

(Step-2) The electron acceptor passes e^- to a chain of ***electrons transport system*** (consisting of cytochromes) and transferred to the pigments of PS I.
The accepter of e^- which is located towards the outer side of the membrane transfers its e^- to an H^+ carrier. Hence, this molecule while transporting an e^- coupled to H^+ transfer into the lumen from the stroma.
This movement of e^- is downhill, in terms of a redox potential scale.

(Step-3) Simultaneously, e^- in PS I are also excited when they receive red light (700 nm) and are transferred to another accepter molecule having a greater redox potential.

(Step-4) These e^- are moved downhill to a molecule of $NADP^+$. As a result, $NADP^+$ is reduced to NADPH $+H^+$.
This transfer of e^-, starting from the PS II, uphill to the acceptor, down the electron transport chain to PS I, excitation of e^-, transfer to another acceptor, and finally down hill to NADP+ causing it to be reduced to NADPH + H^+ is called the ***Z scheme***, due to its characterstic shape.

(Step-5) These steps decrease H^+ in the stroma, while in the lumen there is accumulation of H^+. This develops a H^+ gradient across the thylakoid membrane.
H^+ diffuse back through **ATP synthase** from the lumen into the stroma, produces ATP from ADP and P_i.
(Chemiosmotic hypothesis of ATP synthesis- by Peter Mitchell in 1961, Nobel prize in 1978**).**

➔ **Photo-phosphorylation** is the synthesis of ATP from ADP and P_i in the presence of light.
It occurs in 2 ways- Non cyclic & Cylic.

Difference between Non-cyclic & cyclic phosphorylation

Non-cyclic photo-phosphorylation	Cyclic photo-phosphorylation
1. This system is found dominant in **green plants**.	1. In **bacteria**.
2. Occurs in the thylakoid membrane.	2. Occurs in the stroma lamellae. (Lack PS II as well as NADP reductase enzyme). ➔ Also occurs when only light of wavelengths beyond 680 nm are available for excitation.
3. PS II & PS I work in series and connected through an ETS as seen in Z scheme.	3. Only PS I is functional.
4. It is a non-cyclic process because the e^- lost by PS II does not come back to it but pass on to $NADP^+$.	4. The excited e^- does not pass on to $NADP^+$ but is cycled back to the PS I complex through the ETS.
5. The first step is photo-oxidation of water resulting splitting of water into H^+, e^- and release of O_2.	5. This system is **not concerned** with it.
6. Here ATP & $NADP^+$ are synthesised.	6. It is **only** ATP is synthesised.

II. *Dark reaction* / *Biosynthetic phase*

- This process of producing sugar needs the products of the light reaction, i.e., ATP and NADPH, besides CO_2 and H_2O.
- The process of CO_2 fixation is of 2 types-
  a) C_3 pathway- In this, the first product of CO_2 fixation is a C_3 acid (PGA).
  b) C_4 pathway- In this, the first product is a C_4 acid (OAA).

a) The Calvin Cycle (C_3 pathway)

- The Calvin pathway occurs in **all photosynthetic plants** (in C_4 also).
- It has 3 stages:- Carboxylation, reduction and regeneration.

i) Carboxylation of RuBP

CO_2 (1C) is accepted by **RuBP** (5C) to form 2 molecules of **3-PGA (**3C**)** by the enzyme ***RuBisCO***.

Photorespiration

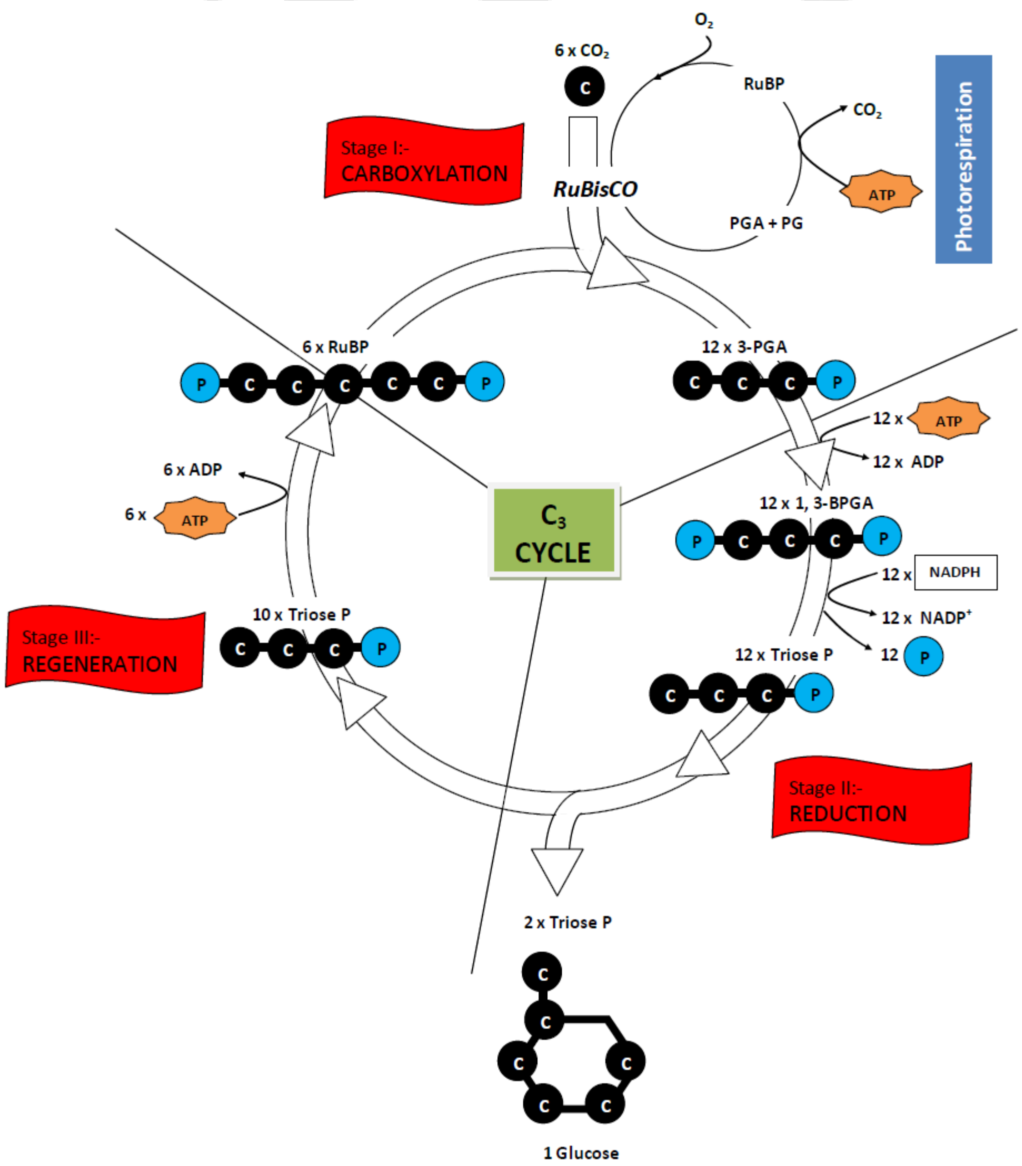
- In C_3 plants, at higher conc. of O_2, ***RuBisCO*** express its oxygenase activity and hence CO_2 fixation is decreased.
- Here the RuBP, instead of being converted to 2 molecules of PGA, binds with O_2 to form 1 molecule of phosphoglycerate (PGA-3C) and phosphoglycolate (PG-2C).
  This pathway is called **photorespiration**. (It is named so as it utilise O_2 and release CO_2).
- In the photorespiratory pathway, 25-50 % CO_2 that is fixed is released with the utilisation of ATP. There is neither synthesis of sugars, nor of ATP. Therefore, photorespiration is a wasteful process.

ii) Reduction

- The fixation of 6 molecules of CO_2 and 6 turns of the cycle are required for the removal of 1 molecule of glucose (6C) from the pathway.
- Here 2 ATP for phosphorylation and 2 NADPH for reduction per CO_2 molecule fixed.

iii) Regeneration of RuBP

- After fixing the CO_2, 6 RuBP is regenerated using 6 ATP by phosphorylation.



b) The Hatch & Slack pathway (C_4 pathway)

- It is present in plants adapted to dry tropical regions.
- C_4 plants are special because:-
  - They have a special type of leaf anatomy
    - ✓ The large cells around the vascular bundles of the C_4 pathway plants are called **bundle sheath cells**. Such anatomy is called **'Kranz' anatomy**. ('*Kranz'* = wreath).
    - ✓ They have a large number of chloroplasts, thick walls impervious to gaseous exchange and no intercellular spaces.
  - They tolerate higher temperatures
  - They show a response to high light intensities
  - They lack photorespiration and hence have greater productivity of biomass.
    - ➔ This is because they have a mechanism that increases the concentration of CO_2 at the enzyme site.
      This takes place when the C_4 acid from the mesophyll is broken down in the bundle sheath cells to release CO_2 – this results in increasing the intracellular concentration of CO_2.
      In turn, this ensures that the RuBisCO functions as a carboxylase minimising the oxygenase activity.

i) Carboxylation of PEP

CO_2 is accepted by 3-C molecule **phosphoenol pyruvate (PEP)** present in the mesophyll cells by the enzyme **PEP carboxylase** (**PEPcase**) to form C_4 acid OAA.
The mesophyll cells lack RuBisCO enzyme.

ii) Transportation

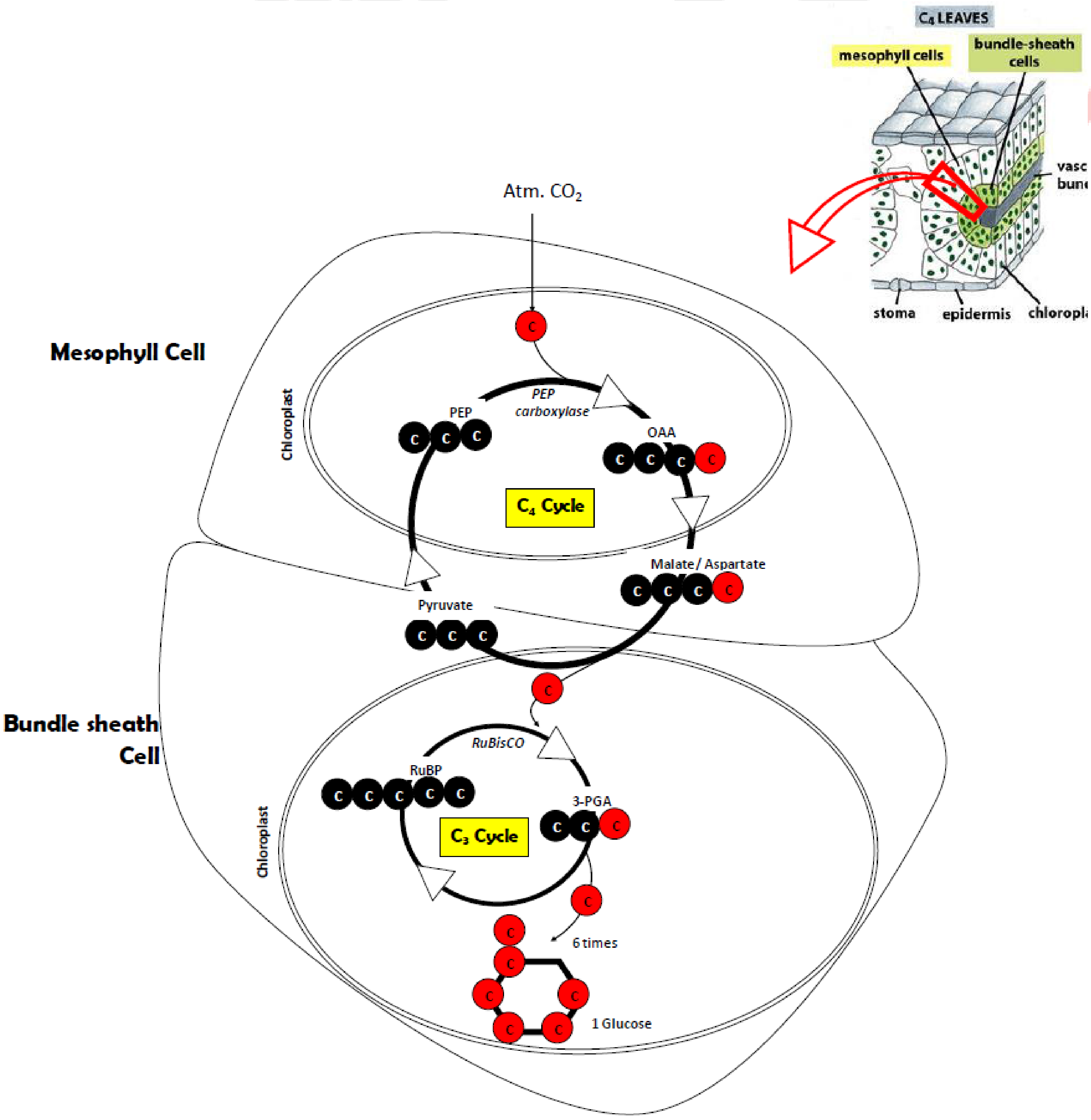
It then forms other 4-C compounds like malic acid or aspartic acid in the mesophyll cells, which are transported to the bundle sheath cells.

iii) Decarboxylation

In the bundle sheath cells these C_4 acids are broken down to release CO_2 and a 3-C molecule.
The CO_2 released in the bundle sheath cells enters the C_3 or the Calvin pathway.

iv) Transportation

The 3-C molecule is transported back to the mesophyll where it is converted to PEP again, thus, completing the cycle.



Differences between C_3 plants & C_4 plants

C_3 plants	C_4 plants
1. Include **most crop** plants such as cereals, beans, tobacco etc.	1. Include **maize, sorghum**, sugarcane, *Amaranthus* etc. (Around 1000 sps.)
2. Leaves do **not exhibit 'Kranz'** anatomy.	2. **Shows**
3. Photosynthesis occurs in mesophyll cells. i.e., Chloroplast is only **1 type**. **Only C_3** pathway is performed by mesophyll chloroplast.	3. In mesophyll and bundle sheath cells. Chloroplast are **2 types-** The mesophyll chloroplast perform **C_4 cycle** and bundle sheath chloroplast perform **C_3 cycle.**
4. Primary CO_2 acceptor is **RuBP**.	4. **PEP**
5. CO_2 fixing enzyme is **RuBP carboxylase.**	5. **PEP carboxylase**
6. The first stable product of photosynthesis is 3C-**PGA**	6. 4C-**OAA**
7. Photorespiratory loss is **high.** **i.e., Less efficient** in utilising atmospheric CO_2.	7. Absent or **Negligible** **More efficient** (even when the stomata are nearly closed).
8. Higher temperature **inhibits CO_2** uptake. Optimum temp. for photosynthesis is 25^0C.	8. **Promotes.** About 35-45^{0}C.

FACTORS AFFECTING PHOTOSYNTHESIS

- Internal (plant) factors:-
  - The number, size, age and orientation of leaves, mesophyll cells and chloroplasts,
  - Internal CO_2 concentration
  - The amount of chlorophyll.

  The plant or internal factors are dependent on the genetic predisposition (i.e., different in different sps.) and the growth of the plant.
- External factors:-
  - The availability of sunlight, CO_2 concentration, temperature & water.

a) Light

- Light **quality**, light **intensity** and the **duration** of exposure to light, affects photosynthesis.
- There is a linear relationship between incident light and CO_2 fixation rates at low light intensities.
- At higher light intensities, gradually the rate does not show further increase as other factors become limiting.
- The optimum light intensity at which photosynthetic rate is maximal is called **Light saturation**. 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 breakdown chlorophyll and a decrease in photosynthesis.

b) CO_2 Concentration

- CO_2 is the major limiting factor for photosynthesis.
- The concentration of CO_2 is very low in the atmosphere (between 0.03 and 0.04 %). Increase in concentration upto 0.05% can cause an increase in CO_2 fixation rates. Beyond this the levels can become damaging over longer periods.
- At low light conditions C_3 and C_4 plants do not responds to high CO_2 conditions.
  At high light intensities, they show increase in the rates of photosynthesis.
- C_4 plants show saturation at about 360 μlL^{-1}
  C_3 responds to increased CO_2 concentration and saturation is seen only beyond 450 μlL^{-1}. Thus, current availability of CO_2 levels is limiting to the C_3 plants.
- Due to higher productivity in higher CO_2 concentration, C_3 plants (such as tomatoes and bell pepper) are allowed to grow in CO_2 enriched atmosphere in some green houses.

c) Temperature

- The dark reactions being enzymatic are temperature controlled. Influence of temperature on light reactions is less.
- The C_4 plants respond to higher temperatures and show higher rate of photosynthesis
- C_3 plants have a much lower temperature optimum.
- The temperature optimum for photosynthesis of different plants also depends on the habitat that they are adapted to. Tropical plants have a higher temperature optimum than the plants adapted to temperate climates.

d) Water

- No direct effect on photosynthesis (Less than 1% of water absorbed by a land plant is utilised for photosynthesis).
- Decrease in water content (**water stress**) causes the stomata to close hence reducing the CO_2 availability.
- Water stress also makes leaves wilt, thus, reducing the surface area of the leaves and their metabolic activity.

- 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 which is nearest to its minimal value: it is the factor which directly affects the process if its quantity is changed.*

PHOTO-SYNTHESIS