Chapter-4 Photosynthesis in Higher Plants

Very Short Answers Questions:

1. Name the processes which take place in the grana and stroma regions of chloroplasts?

A: **Grana**—Light reactions. Trapping light energy, synthesizing ATP and $NADPH_2$.

Stroma—Dark reactions. CO_2 fixation. Sugar and starch formation.

2. Where does the photolysis of H_2O occur? What is its significance?

A: In the inner side (lumen) of the membrane of Thylakoids.

Splitting releases O_2 and electrons. O_2 released into the atmosphere and electrons replace those removed from PS II due to excitation of light. Electron transport through membrane results in the reduction of $NADP^+$ to $NADPH_2$.

3. How many molecules of ATP and NADP are needed to fix a molecule of CO_2 in C_3 plants? Where does this process occurs?

A: 3ATP and 2 $NADPH_2$ are needed for the fixation of single CO_2 molecule.

In the stroma.

4. Mention the components of ATPase enzyme. What is their location? Which part of the enzyme shows conformational change?

A: F_0 & F_1.

F_0 is embedded in the thylakoid membrane. F_1 part protrude outer surface into the stroma.

F1 shows conformational change.

5. Distinguish between action spectrum and absorption spectrum.

A: **Absorption Spectrum:** A graphical representation of absorption of light by various substances (pigments) at different wave lengths.

Action Spectrum: A graph showing the rate of involvement of different pigments (substances) in a particular photoreaction (like photosynthesis, seed germination etc.)

6. Of the basic raw materials of photosynthesis, what is reduced? What is oxidized?

A: CO_2 is reduced to sugars. H_2O is oxidized to electrons, protons & O_2.

7. Define the law of limiting factors proposed by Blackman?

A: "If a process is conditioned as to its rapidity by a number of separate factors, the rate of the process is limited by the factor that is present in a relative minimal value".

8. What is the primary acceptor of CO_2 in C_3 plants? What is first stable compound formed in the Calvin Cycle?

A: Ribulose bisphosphate is the primary acceptor.

3- Phosphoglyceric acid is the first stable compound.

9. What is the primary acceptor of CO_2 in C_4 plants? What is first compound formed as a result of primary carboxylation in the C_4 path way?

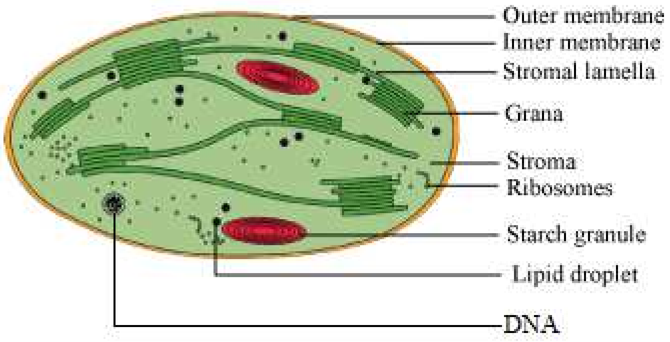
A: Phosphoenolenol pyruvic acid is the primary acceptor.

Oxaloacitic acid is the first stable compound.

Short Answers Questions:

1. Draw a neat labeled diagram of chloroplast.

Ans:



2. Tabulate any eight differences between C_3 and C_4 plants/cycles.

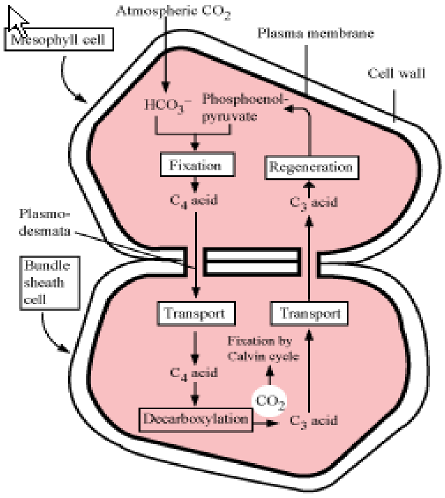
Ans:

	C_3 Plants/Pathway	C_4 Plants/Pathway
1	Occurs mostly in temperate plants and some tropical plants	Occurs only in tropical and subtropical plants.
2	Kranz anatomy not shown by the leaves	Leaves exhibit Kranz anatomy.
3	Only Calvin cycle occurs	C_4 pathway in mesophyll cells and Calvin pathway in bundle sheath cells.
4	The primary CO_2 acceptor is RuBP (5).	The primary CO_2 acceptor is PEP (3)
5	The first compound formed is phosphoglyceric acid a 3C compound.	The first compound formed is oxaloacetic acid a 4C compound.
6	Photorespiration is very high.	Photorespiration is not detectable
7	Less efficient in utilizing atmospheric CO_2	More efficient in utilizing atmospheric CO_2
8	The optimum temperature for this pathway is 15^0C to 25^0C.	The optimum temperature for this pathway is 35^0C to 45^0C.
9	Water use efficiency is low	Water use efficiency is high.
10	Photosynthetic yield is very low.	Photosynthetic yield is very high.

3.Describe C_4 pathway?

Ans: Plants that are adapted to dry tropical regions have the C_4 pathway. These plants have the C_4 oxaloacetic acid as the first CO_2 fixation product they use the C_3 pathway or the Calvin cycle as the main biosynthetic pathway.C_4 plants are special: They have a special type of leaf anatomy.

The particularly large cells around the vascular bundles of the C_4 pathway plants are called **bundle sheath cells**, and the leaves which have such anatomy are said to have **'Kranz' anatomy**. 'Kranz' means 'wreath' and is a reflection of the arrangement of cells. The bundle sheath cells may form **several layers** around the vascular bundles; they are characterised by having a large number of chloroplasts, thick walls impervious to gaseous exchange and no intercellular spaces e.g maize or sorghum.



Hatch and Slack pathways

This pathway also named as Hatch and Slack Pathway, is again a cyclic process.

The primary CO_2 acceptor is a 3-carbon molecule **phosphoenol pyruvate (PEP)** and is present in the mesophyll cells. The enzyme responsible for this fixation is **PEP carboxylase** or PEPcase. Mesophyll cells lack RuBisCO enzyme. The C_4 acid OAA is formed in the mesophyll cells.

It then forms other 4-carbon compounds like malic acid or aspartic acid in the mesophyll cells itself, which are transported to the bundle sheath cells. In the bundle sheath cells these C_4 acids are broken down to release CO_2 and a 3-carbon molecule.

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

The CO_2 released in the bundle sheath cells enters the C_3 or the Calvin pathway, a pathway common to all plants. The bundle sheath cells are rich in an enzyme Ribulose bisphosphate carboxylase-oxygenase **(RuBisCO)**, but lack PEPcase. Thus, the basic pathway that results in the formation of the sugars, the Calvin pathway, is common to the C_3 and C_4 plants.

They tolerate higher temperatures, they show a response to high light intensities, they lack a process called photorespiration and have greater productivity of biomass

4. Describe in brief photorespiration?

Ans: Photorespiration is respiration of green pigment in the presence of light.

RuBisCO that is the most abundant enzyme in the world is characterised by the fact that its active site can bind to both CO_2 and O_2 – hence the name.

RuBisCO has a much greater affinity for CO_2 than for O_2. This binding is competitive. It is the relative concentration of O_2 and CO_2 that determines which of the two will bind to the enzyme.

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 in a pathway called photorespiration.

In the photorespiratory pathway, there is neither synthesis of sugars, nor of ATP. Rather it results in the release of CO_2 with the utilisation of ATP. In the photorespiratory pathway there is no synthesis of ATP or NADPH. Therefore, photorespiration is a wasteful process.

In C4 plants photorespiration does not occur.

Long Answers Questions:

1. In the light of modern researches, describe the process of electron transport, cyclic and non-cyclic photo-phosphorylation?

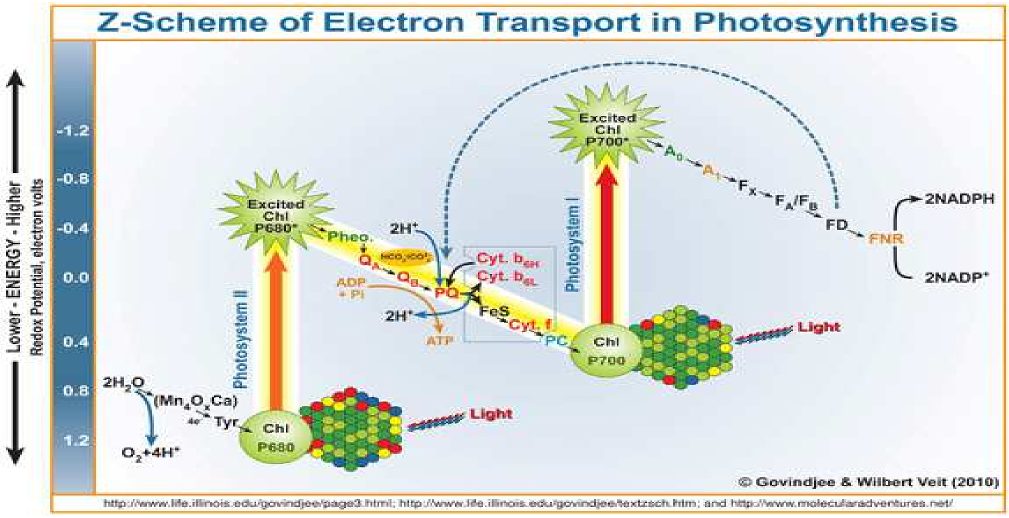
Ans: **The Electron Transport**

Photochemical reaction in which the movement of electron exited from the pigment molecule in the presence of light reducing and oxidizing different protein molecules of the thylakoid membrane in sequential order according to their red-ox potential to release assimilatory power ATP and $NADPH_2$ is called Electron Transport.

Several complexes are involved in the process.

The pigments are organised into two discrete photochemical **light harvesting complexes** (**LHC**) within the **Photosystem I (PS I)** and **Photosystem II (PS II**). The LHC are made up of hundreds of pigment molecules bound to proteins. Each photosystem has all the pigments (except one molecule of chlorophyll *a*) forming a light harvesting system also called **antennae.** 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,** while in PS II it has absorption maxima at 680 nm, and is called **P680**.



In photosystem II the reaction centre chlorophyll *a* absorbs 680 nm wavelength of red light causing electrons to become excited and jump 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.** This movement of electrons is downhill, in terms of an oxidation-reduction or redox potential scale.

The electrons are not used up as they pass through the electron transport chain, but are passed on to the pigments of photosystem PS I. Simultaneously, electrons in the reaction centre of PS I are also excited when they receive red light of wavelength 700 nm and are transferred to another accepter molecule that has a greater redox potential.

These electrons then are moved downhill again, this time to a molecule of energy-rich NADP+.

The addition of these electrons reduces NADP+ to NADPH + H+.

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, transfer to another acceptor, and finally downhill to NADP+ causing it to be reduced to NADPH + H+ is called the **Z scheme**, due to its characterstic shape. This shape is formed when all the carriers are placed in a sequence on a redox potential scale.

Splitting of Water

The splitting of water is associated with the PS II; water is split into H+, [O] and lectrons.This creates oxygen, one of the net products of photosynthesis. The electrons needed to replace those removed from photosystem I are provided by photosystem II.

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

Cyclic and Non-cyclic Photo-phosphorylation

The process through which ATP is synthesised by cells (in mitochondria and chloroplasts) is named phosphorylation.

Photophosphorylation is the synthesis of ATP from ADP and inorganic phosphate in the presence of light. When the two photosystems work in a series, first PS II and then the PS I, a process called **non-cyclic photo-phosphorylation** occurs. The two photosystems are connected through an electron transport chain, as seen earlier – in the Z scheme. Both ATP and NADPH + H+ are synthesised by this kind of electron flow along with the release of Oxygen

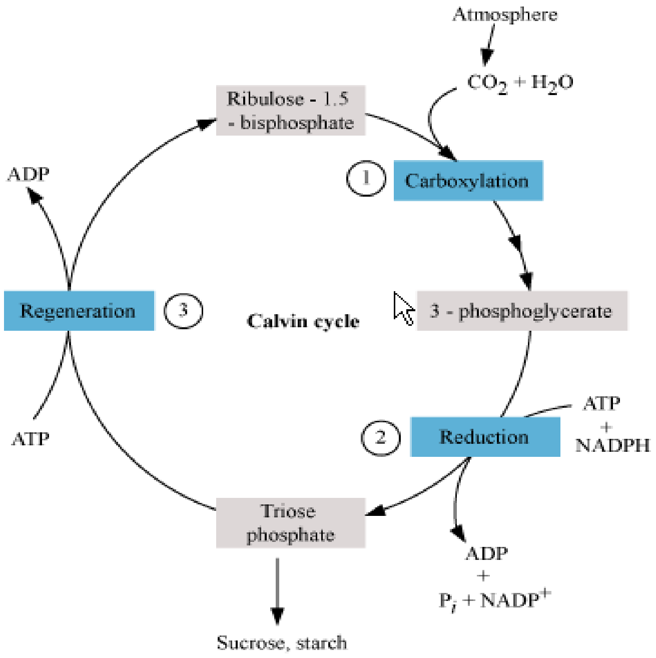
When only PS I is functional, the electron is circulated within the photosystem and the phosphorylation occurs due to **cyclic flow of electrons**. Only **ATP** is synthesized in **cyclic photo-phosphorylation, No Oxygen is released.**

2. Explain Calvin cycle?

Ans: Calvin and his co-workers worked out the whole pathway and showed that the pathway operated in a cyclic manner; the RuBP was regenerated. Calvin pathway occurs in **all photosynthetic plants**; it does not matter whether they have C_3 or C_4 pathways. Calvin cycle can be described under three stages: carboxylation, reduction and regeneration.

1. Carboxylation – Carboxylation is the fixation of CO_2 into a stable organic intermediate. Carboxylation is the most crucial step of the Calvin cycle where CO_2 is utilised for the carboxylation of RuBP. This reaction is catalysed by the enzyme RuBP carboxylase which results in the formation of two molecules of 3-PGA.

Since this enzyme also has an oxygenation activity it would be more correct to call it RuBP carboxylase-oxygenase or **RuBisCO**.



6RUBP + 6CO2 + 6H2O → 12 Phosphoglyceric acid

2. Reduction – These are a series of reactions that lead to the formation of glucose. The steps involve utilisation of 2 molecules of ATP for phosphorylation and two of NADPH for reduction per CO molecule fixed. The fixation of six molecules of CO_2 and 6 turns of the cycle are required for the removal of one molecule of glucose from the pathway.

a. 12 Phosphoglyceric acid + 12 ATP → 12 Bisphosphoglyceric acid + 12 ADP
enzyme being *Phosphoglycerokinase*

b. 12 Bisphosphoglyceric acid + 12 NADPH → 12 Glyceraldehude-3-phosphate(G-3-P) + 12 $NADP^+$ + 12 H_2PO_4
Enzyme being *G-3-P dehydrogenase*

(Of the 12 G-3-P net gain is 2; 10 G-3-P are used to regenerate 6 RuBP)

3. Regeneration – Regeneration of the CO2 acceptor molecule RuBP is crucial if the cycle is to continue uninterrupted.

The regeneration steps require one ATP for phosphorylation to form RuBP.

G-3-P and DHAP are isomers in the presence of enzyme *triose phosphate isomerase.*

a. 2 G-3-P + 2 DHAP → 2 Fructose-1-6-bisphosphate
Enzyme being *Aldolase*

b. 2 Fructose-1-6-bisphosphate → 2 Fructose-6-phosphate +2Pi
Enzyme being *Fructose-1-6-bisphosphate kinase*

c. 2 Fructose-6-phosphate + 2 G-3-P → 2 Xylulose-5-Phosphat(X-5-P) +2 Erythrose-4- phosphate(E-4-P)
Enzyme being *Transketolase*

d. 2(E-4-P) + 2 DHAP → 2 Sedoheptulose-1-7-bisphosphate.
Enzyme being *Aldolase*

e. 2 Sedoheptulose-1-7-bisphosphate → 2 Sedoheptulose-7-bisphosphate + 2Pi
Enzyme being *Sedoheptulose-1-7-bisphosphatase*

f. 2 Sedoheptulose-7-bisphosphate + 2 G-3-P → 2 Xylulose-5-phosphate +2 Ribose-5-phosphate

Enzyme being *Transketolase*

g. 4 Xylulose-5-phosphate → 4 Ribulose-5-phosphate

Enzyme being *Ribulose-5-phosphate epimerase*

h. 2 Ribose-5-phosphate → 2Ribulose-5-phosphate

Enzyme being *Ribulose-5-phosphate isomerase*

i. 6 Ribulose-5-phosphate + 6 ATP → 6 Ribulose-1-5-bisphosphate + 6 ADP

Enzyme being *Ribulose-5-phospho kinase*

Hence for every CO_2 molecule entering the Calvin cycle, 3 molecules of ATP and 2 of NADPH are required.

To make one molecule of glucose 6 turns of the cycle are required.

A total of 18 ATP and 12 NADPH are required for 6 CO_2