11 Photosynthesis in Higher Plants

Have you ever seen someone fainting in your school assembly, and giving that person glucose as primary aid? Have you ever thought why not plants faint or how they wilt, from where do they get their energy, their glucose! Plants produce oxygen and provide food for all animals on the planet. Photosynthesis is important due to two reasons: It is the primary source of all food on earth. It is also responsible for the release of oxygen into the atmosphere by green plants. You will gain a better understanding of how plants provide these life-sustaining components by learning about photosynthesis.

Topic Notes

- *Photosynthesis and Electron Transport*
- *C_3 and C_4 Plants*

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PHOTOSYNTHESIS AND ELECTRON TRANSPORT

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TOPIC 1

PHOTOSYNTHESIS

Photosynthesis can be defined as an enzyme-regulated anabolic process of manufacturing organic compounds inside the chlorophyll containing cells using carbon dioxide and water with the help of sunlight as a source of energy.

The organisms which perform photosynthesis are called photoautotrophs. They include green plants, red algae, brown algae, green algae, several types of protists, cyanobacteria and some bacteria as well. Phototrophic bacteria employ hydrogen donors other than water.

Key Features of Photosynthesis

Following is the empirical equation which represents the total process of photosynthesis for oxygen releasing organisms:

$$CO_2 + H_2O \xrightarrow{\text{Light}} [CH_2O] + O_2$$

[CH_2O is carbohydrate]

Cornelius van Niel discovered that photosynthesis is a light dependent process in which oxidation of oxygen (H_2O) or hydrogen donor and reduction of carbon dioxide into carbohydrate takes place, this can be represented by the following equation:

$$2H_2A + CO_2 \xrightarrow{\text{Light}} 2A + CH_2O + H_2O$$

The process of photosynthesis can be represented by the following equation:

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

[$C_6H_{12}O_6$ is glucose]

Where Does Photosynthesis Takes Place?

Main site of photosynthesis is green parts of plants, *i.e.* chloroplast. Higher plants have discoid and lens-shaped chloroplasts.

Structure of Chloroplast

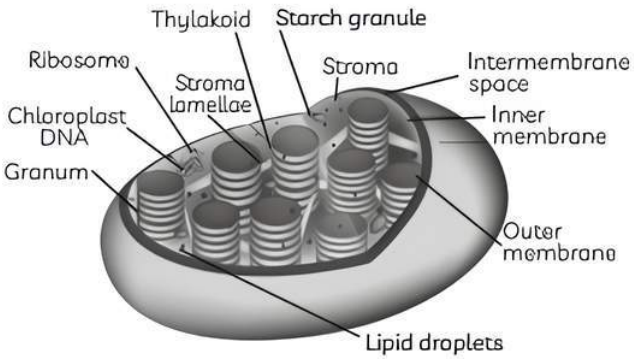
A double membrane surrounds the chloroplast. Within the stroma is a chlorophyll system with a double-membrane sac. There are thylakoids in the stroma. To make grana, they are piled one on top of the other. Thylakoids are individual sacs within each granum. Chlorophylls, carotenes, and xanthophylls are all pigments found in thylakoid membranes. These pigments are fat soluble and are found in the lipid component of the membrane, as well as absorbing light in the visible region of spectrum.

Important

➥ *The mesophyll cells in the leaves contain a large number of chloroplasts, which are responsible for carbon fixation.*

Membranous System consists of:

(1) Grana
(2) Stroma lamellae
(3) Matrix stroma



Diagrammatic Representation of an Electron Micrograph of a Section of Chloroplast

Functions of membranous system are:

(1) Trapping solar energy.
(2) Synthesis of assimilatory powers, *i.e.* ATP and NADPH.

Solar energy is trapped by chlorophyll pigment and stored as chemical energy in the form of ATP and reducing power in the form of NADPH in the photochemical phase of photosynthesis known as light reaction. Water splitting produces oxygen in the light reaction. An electron is raised to a higher energy level when a photon is absorbed by a chlorophyll molecule. A photon must have a particular amount of energy termed quantum energy in order to boost an electron. When a molecule absorbs a photon, it enters an energy-rich excited state. When the light source is turned off, the high-energy electrons quickly return to their usual low-energy orbitals, reverting the excited molecule to its original stable form, known as the ground state.

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The biochemical phase of photosynthesis known as dark reaction does not depend on light directly, but is dependent on products of light reaction (ATP and NADPH). A sequence of enzyme-catalyzed events takes place in the stroma lead to carbon fixation. Molecules of ATP and NADPH are generated in the thylakoids during light reactions used in the stroma where carbohydrates are synthesised. The stroma is the place where carbohydrates are synthesised by using ATP and NADPH produced inside the thylakoids during light reaction Calvin, Benson and their colleagues discovered the process of carbon fixation in the dark reaction, that leads to the formation of sugar and starch *via* intermediary molecules. Calvin was awarded the Nobel Prize for this discovery in 1961.

How Many Pigments are Involved in Photosynthesis?

Chlorophyll is a green pigment found in plants. It has a significant role to perform, like, it provides green colour to plants. The chloroplast of the mesophyll cells of leaves contains it. They can absorb solar energy and use it to convert carbon dioxide to carbohydrates (food). Chlorophyll not only aids in the collection of sunlight by plants, but it also aids in the release of oxygen by plants. Water splitting complex or oxygen evolving complex which is located on inner side of thylakoid membrane is responsible for splitting of water and releasing of oxygen. Chlorophyll *a* and chlorophyll *b* are the two kinds of chlorophyll. Accessory pigments include chlorophyll *b*, xanthophyll, and carotenoids absorb light and transfer the energy to chlorophyll *a* because it is primary pigment. These accessory pigments work as shield pigments because they protect chlorophyll *a* from photooxidation.

Paper chromatography: It is a technique used in plants to identify different pigments in the leaf.

To separate the different pigments by paper chromatography following steps are followed:

(1) Concentrate the extracted chlorophyll solution by evaporation.

(2) Apply a drop of it at one end, 2 cm away from edge of a strip of chromatography paper and allow it to dry thoroughly.

(3) Take a mixture of petroleum ether and acetone in the ratio of 9: 1 at temperature of 40°C to 60°C.

(4) Hang the strip in the jar with its loaded end dipping in the solvent.

(5) Close the jar tightly and keep it for an hour.

(6) The pigments separate into distinct green and yellow bands of chlorophyll and carotenoid respectively.

Table: Four Major Pigments

Type of Pigment	Name of Pigment	Colour	Function
Chief Pigment	Chlorophyll *a*	Bright or blue-green	Absorption of light.
Thylakoid pigments / Accessory pigments	Chlorophyll *b*	Yellow-green	Absorption of light and pass energy to chloro-phyll *a*.
	Xanthophyll	Yellow	
	Carotenoid	Yellow to yellow-orange	

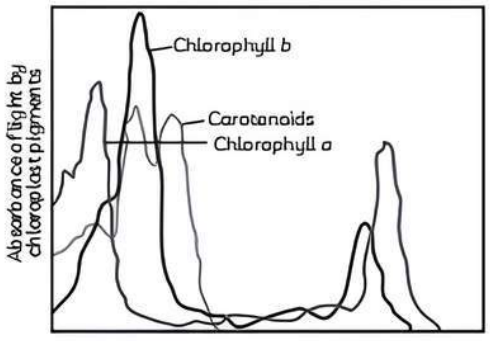
Absorption and Action Spectrum

All photosynthetic pigments have the ability to absorb light of various wavelengths. A graph can be used to show how much light is absorbed by different pigments at different wavelengths. Absorption spectrum is a graph that shows the absorption of light at different wavelengths by different pigments.

The absorption spectrum of chlorophyll *a* and *b* clearly reveals that more light is absorbed in the visible spectrum's blue, violet, and red wavelengths. The action spectrum is a graph that depicts the rate of photosynthesis at various wavelengths of light. The absorption spectra of chlorophyll *a* and *b* show a close association with the relative rate of photosynthesis at different wavelengths.

The wavelengths of light absorbed (red and blue) by chlorophyll pigments are remarkably comparable to the wavelengths that cause photosynthesis, and according to a comparison of the absorption spectrum for chlorophyll pigments and the action spectrum for chlorophyll pigments, the absorption and action spectra are very similar. To look at it another way, the absorption and action spectra of chlorophyll *a* and *b* are identical.

An overlapping of action spectrum of photosynthesis over absorption spectrum of chlorophyll *a*, states that most of the photosynthesis occurs in the red and blue regions of the spectrum and some photosynthesis occurs at the other wavelengths of the visible spectrum.



Graph showing the absorption spectrum of chlorophyll a, b and the carotenoids

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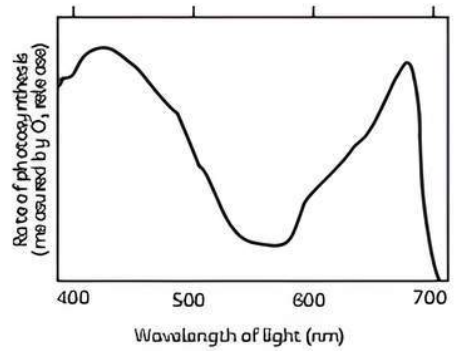
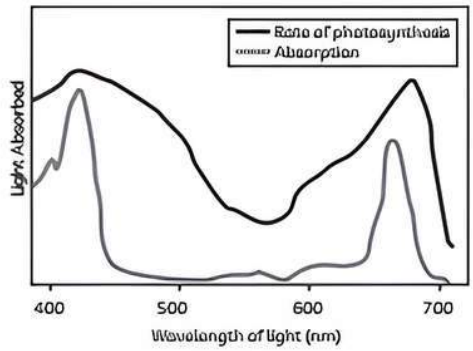


Graph showing action spectrum of photosynthesis



Graph showing action spectrum of photosynthesis superimposed on absorption spectrum of chlorophyll

Example 1.1: Give the differences between Active Spectrum and Absorption Spectrum.

Ans.

Action Spectrum	Absorption Spectrum
The action spectrum is a graph that depicts the rate of photosynthesis at various wavelengths.	The absorption spectrum is a graph that displays how much light is absorbed by pigments at different wavelengths.
It clarifies the link between photosynthetic activity and different light wavelengths.	It describes the link between light quality and pigment absorbing capacity.
Here, the rate of photosynthesis is counted as amount of CO_2 fixation, oxygen production, and NADP reduction.	A spectrophotometer can quantify the absorption of different wavelengths of light pigments in an absorption spectrum.

TOPIC 2

WHAT IS LIGHT REACTION?

We're all aware that photosynthesis requires the presence of sunlight. Did you know, though, that chloroplast absorbs only the blue and red light wavelengths from the sun? Yes, you are accurate. Let's have a look at how the Light Reaction works.

In the chloroplast of the mesophyll cells of the leaves, a light-dependent process takes place. The chloroplasts are double-membraned cell organelles made up of thylakoids, which are stacked disc-like structures. The pigment chlorophyll, which is essential for the process, is found on the membrane of these thylakoids, where the light reaction takes place.

The light reaction's main objective is to produce organic energy molecules like ATP and NADPH, which are required for the dark reaction.

The red and blue segments of white light are absorbed by chlorophyll, and photosynthesis is high at these wavelengths. The photosynthetic pigments are arranged in Light Harvesting Complex. Light Harvesting Complex (LHC) is a pigment bounded protein molecule. It is of two types: PS I and PS II.

When light strikes a plant, the chlorophyll pigment absorbs it and the electrons within it, are activated. This activity takes place within a photosystem, which is a complicated protein system. PS I and PS II are two photosystems that are intimately connected. The excited chlorophyll pigments give up their electrons, and water is split to release four H^+ ions, four electrons, and oxygen to compensate for the loss of electrons. The electrons that escape the PS II are transferred to an electron transfer chain or ETC. Finally, the electrons are used to form NADPH. While electrons are dealt with the accumulation of H^+ ions within the thylakoid lumen is equally important. The hydrogen ions that accumulate inside the lumen generate a positive gradient, and when the enzyme ATP synthase is present, these H^+ ions interact with ADP in the surrounding area to make ATP. The waste product oxygen is released into the atmosphere by the plant, and some of it is utilised in photorespiration if the plant requires it.

Light reaction/ Photochemical phase consists of:

(1) Absorption of light
(2) Photolysis of water
(3) Release of oxygen
(4) Formation of ATP and NADPH
(5) Formation of high energy chemical intermediates.

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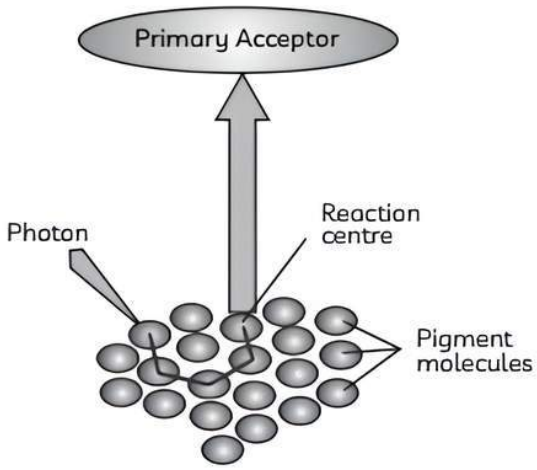

Light harvesting complex

Table: Difference between PS I and PS II

S. No.	Photosystem I	Photosystem II
(1)	The system is located in the non-appressed part of grana thylakoids as well as stroma thylakoids.	Photosystem II is present in the appressed part of granal thylakoids.
(2)	Chlorophyll to carotenoid ratio is high.	Chlorophyll to carotenoid ratio is low.
(3)	Chlorophyll *a* content is more than twice that of chlorophyll *b*.	Chlorophyll *a* and chlorophyll *b* are approximately equal.
(4)	Its photocentre is P_{700}.	Its photocentre is P_{680}.
(5)	It receives electrons from photosystem II.	Electrons are received from photolytic reaction.
(6)	Photosystem I can perform cyclic photophosphorylation independently.	It performs non-cyclic photophosphorylation in conjuction with photosystem I.
(7)	It is not connected with photolysis of water.	Photosystem II is connected with photolytic oxidation of water.
(8)	Usually, it hands over its electron to $NADP^+$.	Usually, it hands over its electron to PS I.

TOPIC 3

THE ELECTRON TRANSPORT

The electron transport chain is a series of electron carriers (groups of proteins) over which electrons pass in a downhill pathway releasing energy at every step. This energy is used to create a proton gradient which helps in the production of ATP (Adenosine Triphosphate). This ATP is used for cellular function in metabolic activities. A proton gradient is formed throughout the process when protons are pushed from the mitochondrial matrix into the cell's intermembrane space, which also aids in ATP synthesis.

Because it relies on a higher concentration of protons to generate "proton motive force," the usage of a proton gradient is sometimes referred to as the chemiosmotic mechanism that drives ATP production. The number of protons pumped across the inner mitochondrial membrane is exactly proportional to the amount of ATP produced. The electron transport chain is made up of a succession of redox processes in which electrons are transferred from a source molecule to an acceptor molecule *via* protein complexes.

The proton gradient is created as a result of these reactions, allowing mechanical work to be transformed into chemical energy and produces ATP. In eukaryotes, the complexes are embedded in the cristae, the inner mitochondrial membrane. Transfer of electrons takes place from high energy to low energy and low potential to high potential.

Splitting of Water

Splitting of water provides new electrons to photosystem II, water molecules are split into three main components, namely, protons, electrons and oxygen, respectively. Protons from splitting water are used as components of reaction that makes NADPH. Electrons formed in water splitting replace electrons that are lost in PS II. Oxygen formed is liberated into the atmosphere.

Important

- *Location of splitting of water: Thylakoid membrane's inner side.*
- *Provides electrons to PS II*

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

Cyclic Photophosphorylation and Non-cyclic Photophosphorylation

When photosystem I is illuminated, electrons move out of and back into the reaction centre of the photosystem. The photophosphorylation of ADP to create ATP occurs in tandem with the cyclic electron flow named Cyclic photophosphorylation. Because

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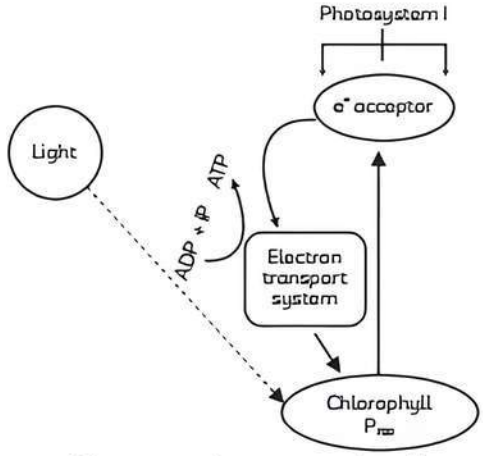
only photosystem I is involved in this process, photolysis of water and the subsequent evolution of oxygen does not occur.

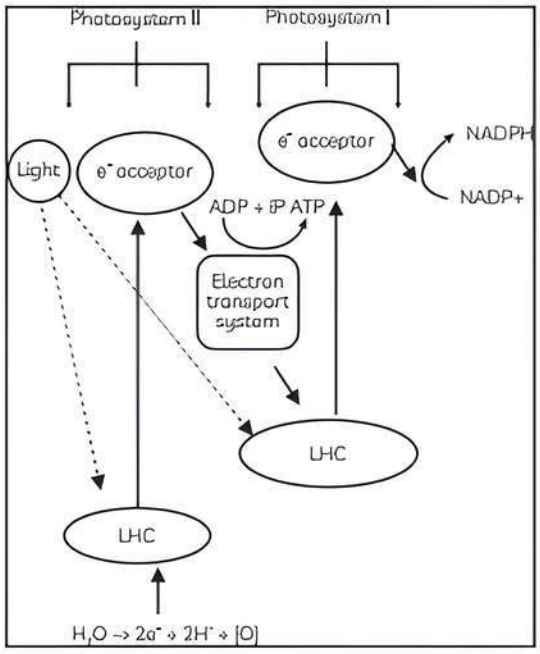


Diagrammatic representation of cyclic photophosphorylation

Non-cyclic photophosphorylation involves both PS I and PS II photosystems. The electron transport chain begins with the release of electrons from PS II in this situation.

High-energy electrons emitted from PS II do not return to PS II in this chain, but instead reach PS I through an electron transport chain, where they are donated to convert NADP to NADPH. In the dark process, the reduced NADP (NADPH) is used for CO_2 reduction. The oxidation of water molecules is caused by electron-deficient PS II.

Protons, electrons, and oxygen atoms are all liberated as a result. PS II takes up electrons to revert to a reduced state, while NAD accepts protons and oxygen is liberated. As a result of this mechanism, high-energy electrons liberated from PS II do not return to PS II, and ATP is formed. This process is called non-cyclic photophosphorylation.



Diagrammatic representation of non-cyclic photophosphorylation

Example 1.2: Differentiate between Cyclic and Non-cyclic photophosphorylation.

Ans.

S. No.	Cyclic Photophosphorylation	Non-Cyclic Photophosphorylation
(1)	It is performed by photosystem I independently.	It is performed by collaboration of both photosystems I and II.
(2)	An external source of electrons is not required because the same electrons get recycled.	The process required an external electron donor.
(3)	It is not connected with photolysis of water. Therefore, no oxygen is evolved.	It is connected with photolysis of water and liberation of oxygen.
(4)	It synthesises only ATP.	Non-cyclic photophosphorylation is not only connected with ATP synthesis but also the production of NADPH.
(5)	It operates under low light intensity, anaerobic conditions or when CO_2 availability is poor.	Non-cyclic photophosphorylation takes place under optimum light, aerobic conditions and in the presence of CO_2.
(6)	The system does not take part in photosynthesis except uncertain bacteria.	The system is connected with CO_2 fixation in all plants.
(7)	It occurs mostly in stromal or intergranal thylakoids.	It occurs in granal thylakoids.

Chemiosmotic Hypothesis

It was proposed by Mitchell (1961). Electron transport, both in respiration and photosynthesis produces a proton gradient. The gradient develops in the outer chamber or inter-membrane space of mitochondria and inside the thylakoid lumen in chloroplasts.

(1) Luman of thylakoid becomes enriched with H^+ ion due to photolytic splitting of water.

(2) Primary acceptor of electron is located on the outer side of thylakoid membrane. It transfers its electrons to an H-carrier. The carrier removes a proton from matrix while transporting electrons to the inner side of the membrane. The proton is released into the lumen while the electron passes to the next carrier.

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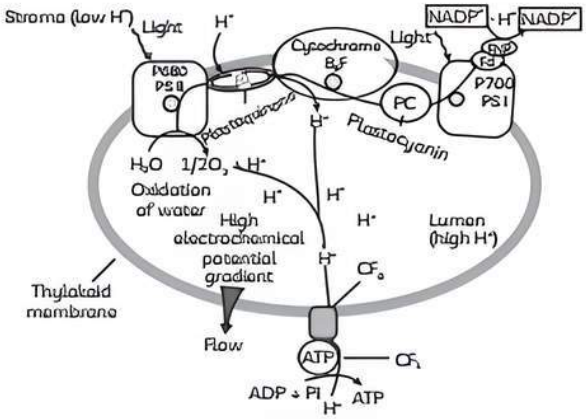
(3) NADP reductase is situated on the outer side of thylakoid membrane. It obtains electrons from PS I and protons from matrix to reduce NADP° to NADP + H° state.

The consequence of the three events is that the concentration of protons decreases in matrix or stroma regions while their concentration in the thylakoid lumen rises resulting in a decrease in pH.

A proton gradient develops across the thylakoid. The proton gradient is broken down due to the movement of protons through transmembrane channels, CFO of ATPase (CF_0 – CF_1 particle). The rest of the membrane is impermeable to H^+ Ions. CF_0 provides facilitated diffusion to H° or protons. As protons move to the other side of ATP, they bring about confirmation change in CF_1 or ATPase or coupling factor. The transient CF_1 particle of ATPase enzyme form ATP from ADP and in organic phosphate.

Therefore, ATP synthesis through chemiosmosis requires a membrane, a proton pump, a proton gradient or high concentration of H^+ ions in the lumen. Proton diffuses across CF_0 channels and releases energy that activates ATPase enzyme to catalyse ATP. One molecule of ATP is formed when $2H^\circ$ passes through ATPase.



ATP synthesis through chemiosmosis

Table: Differences between CF_0 and CF_1

Points	CF_0	CF_1
Location	Submerged in thylakoid membrane.	Outer surface of thylakoid membrane.
Function	Forms a transmembrane channel that allows protons to diffuse more easily across the membrane.	Causes the enzyme to produce a large number of energy-dense ATP molecules.

Important

➥ *ATP synthesis through chemiosmosis requires a Membrane, Proton pump, Proton gradient and ATP synthase.*

OBJECTIVE Type Questions

[1 mark]

Multiple Choice Questions

1. Which metal ion is a constituent of chlorophyll?

(a) Iron (b) Copper
(c) Magnesium (d) Zinc

[NCERT Exemplar]

Ans. *(c) Magnesium*

Explanation: Chlorophyll consists of carbon, hydrogen, oxygen, nitrogen and magnesium. Chlorophylls are the green photosynthetic pigments. Five types of chlorophylls occur in plants other than bacteria — Chlorophyll *a*, Chlorophyll *b*, Chlorophyll *c*, Chlorophyll *d*, Chlorophyll *e*. Structure of chlorophyll consists of a head called porphyrin made up of four pyrrole rings and a phytol tail made up of long chain of alcohol. A magnesium atom which is non-ionic is held in the centre of porphyrin head by nitrogen atoms of pyrrole rings. Phytol is an insoluble long chain of carbon and hydrogen atoms. Chlorophyll *b* differs from chlorophyll *a* in having a formyl group (–CHO) instead of a methyl ($–CH_3$) group at 3rd carbon atom.

Related Theory

➥ *Chlorophyll e is a rare type of chlorophyll found in some golden algae.*

2. Lycopene, a carotenoid pigment, is present in:

(a) Tomato (b) Carrot
(c) Chillies (d) All of these

Ans. *(d) All of these*

Explanation: Carotenes are hydrocarbons made up of 40 carbon and 56 hydrogen atoms. The carotene lycopene is responsible for the red colour of tomatoes, carrots, and chillies. Beta-carotene is the most common carotene. Animals and humans both convert beta-carotene into vitamin A.

3. Membranous system of chloroplast consists of:

(a) Grana (b) Stroma lamellae
(c) Matrix stroma (d) All of these

Ans. *(d) All of these*

Explanation: Grana, stroma lamellae and stroma matrix together form a membranous

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system of chloroplast. Grana is a stacked structure of double membrane sacs or lamellae. Thylakoids are the individual sacs within each granum. Stroma is a proteinaceous liquid matrix enclosed by a chloroplast envelope, it acts as a site of dark reaction of photosynthesis. Stroma lamellae are membranous structures present in between grana, it acts as interconnection between grana and stroma lamellae are also known as fret channels.

4. Which of the following statements are correct?

(I) Light reaction is also known as carbon reaction.

(II) Dark reaction is also known as photochemical reaction.

(III) Light reaction is also called photochemical reaction.

(IV) Dark reaction is also called carbon reaction.

Options:

(a) Statements (I), (II), (III) are correct.

(b) Statements (II) and (III) are correct.

(c) Statements (III) and (IV) are correct.

(d) Statements (IV), (I), (III) are correct.

Ans. *(c) Statements (III) and (IV) are correct.*

Explanation: Because the earlier class of reactions is directly light-driven, they are referred to as light reactions (photochemical reactions). The latter is dependent on light's products rather than being directly light-driven. As a result, they are referred to as dark reactions to distinguish them from the latter (carbon reactions). This does not, however, imply that they occur in the dark or that they are not light-dependent.

5. Which of the following are included in the photochemical phase or light reaction?

Oxygen absorption, light absorption, water absorption, ATP, NADPH, FADH and water splitting.

(a) Oxygen absorption, water splitting, ATP.

(b) ATP, water splitting, NADPH, light absorption.

(c) FADH, ATP, water splitting, NADPH, light absorption.

(d) Water absorption, water splitting, light absorption.

Ans. *(b) ATP, water splitting, NADPH, light absorption.*

Explanation: Certain protein complexes, absorption of light, ATP, NADPH and splitting of water are included in the photochemical phase or Light reaction. Photochemical phase takes place inside the thylakoids, especially in those of the grana region. Photochemical phase is dependent upon light. The function of this photochemical phase is to produce assimilatory power consisting of energy- rich ATP molecules and reduced coenzyme NADPH.

6. Phycocyanin, Allophycocyanin and Phycoerythrin are types of:

(a) Xanthophyll **(b) Carotenoid**

(c) Phycobilin **(d) Chlorophyll *a***

Ans. *(c) Phycobilin*

Explanation: Phycocyanin, Allophycocyanin and Phycoerythrin are types of phycobilin pigment. There are two types of phycobilin pigments, blue and red. Phycocyanin and Allophycocyanin are blue and Phycoerythrin is red. The pigments are useful for chromatic adaptation and also act as important accessory pigments in red algae, cryptomonas and blue-green algae.

7. Chemiosmosis requires all of the following except:

(a) Electron pump **(b) Proton gradient**

(c) Proton pump **(d) ATP synthase**

Ans. *(a) Electron pump*

Explanation: Proton pump, a gradient of proton, a membrane and ATP synthase are required for chemiosmosis. Chemiosmosis hypothesis is the production of ATP by ATP synthase in an electron transport chain. As per the chemiosmosis hypothesis ATP are produced due to proton gradients, formed inside the thylakoid membrane.

Related Theory

➥ *Chemiosmotic hypothesis was proposed by Peter Mitchell.*

8. Choose the correct option regarding biosynthetic phase.

(a) This process depends on light.

(b) This process does not depend on products of light reaction.

(c) It stops immediately when the light is not available.

(d) It depends on ATP and NADPH.

Ans. *(d) It depends on ATP and NADPH.*

Explanation: Biosynthetic phase does not depend directly on light and continues for sometime even when light is not available. It mainly depends on the products of the photochemical phase that are ATP and NADPH.

9. Dark reaction in photosynthesis is called so because:

(a) It can occur in dark.

(b) It does not directly depend on light energy.

(c) It cannot occur during daylight.

(d) It occurs more rapidly at night.

[NCERT Exemplar]

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Ans. *(b) It does not directly depend on light energy.*

Explanation: The biosynthetic step catalyzes carbon dioxide assimilation into carbohydrates. Carbon reactions are what they're called. They can be found in the stroma of chloroplasts. The rationale does not necessitate the use of light. Instead, ATP and NADPH are employed in carbon dioxide fixation and reduction.

Caution

Students should know that as per the name of dark reaction, it does not takes place in dark, rather it requires products of light reaction. It continues for some time after light because unavailable.

10. Statement A: Both PS I and PS II are located on differential faces of thylakoid membrane.

Statement B: Photolysis of water takes place in lumen.

(a) Both A and B are correct.
(b) Both A and B are incorrect.
(c) Only A is correct.
(d) Only B is correct.

Ans. *(a) Both A and B are correct.*

Explanation: Photosynthesis-related pigments and coupling agents can be found in thylakoid membranes. They exist in certain populations known as photosystems (previously quantasomes). Two photosystems exist. The stroma lamellae lack PS II and the NADP reductase enzyme while the grana lamellae have both PS I and PS II. Photolysis of water takes place in lumen while reduced $NADP^*$ is used, in stroma, for reduction of CO_2.

11. Which is the correct colour matching in chromatogram?

(a) Chlorophyll *a* – yellow-green
(b) Chlorophyll *b* – yellow-orange
(c) Xanthophyll – yellow
(d) Carotenoids – bright or blue-green

Ans. *(c) Xanthophyll – yellow*

Explanation: Xanthophyll shows a yellow colour. Chlorophyll *a* shows bright or blue - green colour whereas chlorophyll *b* shows yellow–green. Carotenoids show varying colours from yellow to yellow–orange.

12. Complete the reaction.

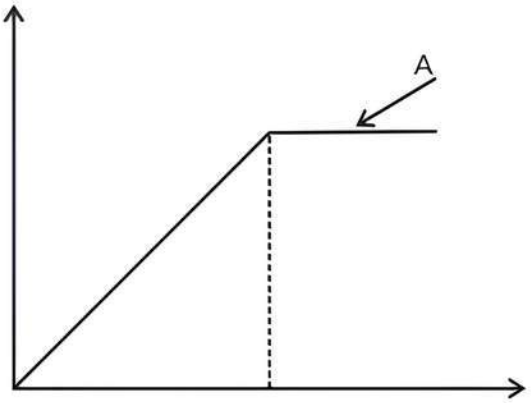
$$RuBP + CO_2 \rightarrow$$

(a) 3 × 3PGA
(b) 2 × 3PGA
(c) 2 × 3PGA + RuBisCO
(d) 3 × 3PGA + RuBisCO

Ans. *(b) 2 × 3PGA*

Explanation: The given reaction is that of the first step of the Calvin cycle, carbon dioxide fixation. RuBP combines with carbon dioxide to form two molecules of 3PGA. RuBisCO is an enzyme that catalyses the reaction.

13. A portion of the graph 'Rate of photosynthesis vs. Light intensity' is labelled 'A'. What causes 'A'?



(a) Increase in light intensity
(b) Decrease in light intensity
(c) Opening of stomata
(d) Closing of stomata

Ans. *(a) Increase in light intensity*

Explanation: In the graph 'Rate of photosynthesis vs. Light intensity', the portion labelled 'A' implies that with an increase in the light intensity, the rate remains constant after some time and does not increase.

14. What is the correct sequence?

(I) Antenna molecule 700
(II) NADPH
(III) PSI
(IV) PSII
(V) Thylakoid membrane

Options:

(a) (I), (II), (III), (IV), (V)
(b) (II), (III), (IV), (I), (V)
(c) (V), (IV), (III), (I), (II)
(d) (V), (III), (IV), (I), (II) **[Delhi Gov. QB 2022]**

Ans. *(c) (V), (IV), (III), (I), (II)*

Explanation: The sequence is Thylakoid membrane → PS II → PS I → Antenna molecule 700 → NADPH.

Assertion-Reason (A-R)

Given below are two statements labelled as Assertion (A) and Reason (R). Select the most appropriate answer from the options given below:

(a) Both A and R are true and R is the correct explanation of A.
(b) Both A and R are true and R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

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15. **Assertion (A):** **Photosystem II is also known as P_{680}.**

Reason (R): **Maximum absorption in PS II takes place at wavelength 680 nm.**

Ans. *(a) Both A and R are true and R is the correct explanation of A.*

Explanation: Photosystem II is known as P_{680} because maximum absorption here occurs at wavelength 680 nm.

16. **Assertion (A):** **As electrons move through the photosystems, protons are transported across the membrane.**

Reason (R): **The primary acceptor of an electron which is located towards the outer side of the membrane transfers its electron not to an electron carrier but to an H^+ carrier.**

Ans. *(a) Both A and R are true and R is the correct explanation of A.*

Explanation: As electrons move through photosystems, protons are exchanged across the membrane. Because the principal electron acceptor on the membrane's outer side sends its electron to a hydrogen carrier rather than an electron carrier, this happens. As a result, this molecule carries an electron from the stroma while withdrawing a proton.

17. **Assertion (A):** **The splitting of water is associated with the PS II.**

Reason (R): **The electrons needed to replace those removed from photosystem II are provided by photosystem I.**

Ans. *(c) A is true but R is false.*

Explanation: The PS II is linked to the splitting of water. Photosystem II provides the electrons required to replace those destroyed from photosystem I.

18. **Assertion (A):** **In terms of the redox potential scale, movement of electrons is downhill.**

Reason (R): **Electrons in the reaction centre of PS I excite when they receive blue light of wavelength.**

Ans. *(c) A is true but R is false.*

Explanation: When electrons in PS I's reaction centre are exposed to wavelength red light, they are also excited.

19. **Assertion (A):** **For the formation of one molecule of glucose, 6 molecules of CO_2 and 12 molecules of $NADPH^\bullet + H^+$ and 18 ATP are used.**

Reason (R): **In light reaction, ATP and $NADPH_2$ are formed.**

[Delhi Gov. QB 2022]

Ans. *(b) Both A and R are true and R is not the correct explanation of A.*

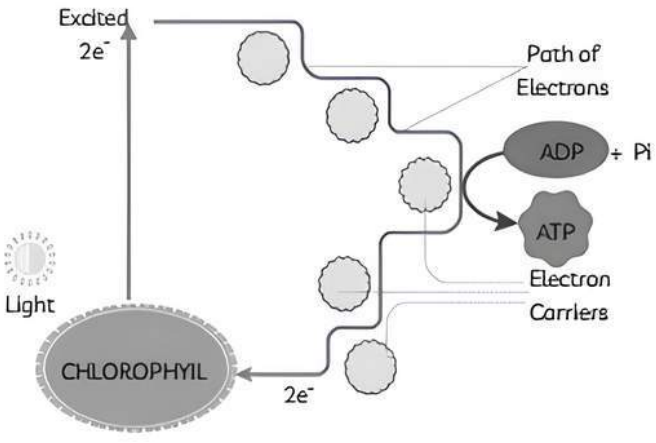
Explanation: In light reactions, organic energy molecules like ATP and NADPH are formed, which are required for dark reactions.

CASE BASED Questions (CBQs)

[**4** & **5** marks]

Read the following passages and answer the questions that follow:

20. *The phenomenon of cyclic electron transport was first characterised in higher plant chloroplasts 50 years ago, yet there is still a debate about whether or not this is a physiological process. The recent isolation of mutants that appear to lack cyclic electron transport, as well as new data providing functional evidence for its occurrence, support the notion that this pathway plays an important role in plant responses to stress, providing a pH gradient across the thylakoid membrane to trigger non-photochemical quenching of chlorophyll fluorescence. At present, little is known about the regulation of cyclic electron transport, but it is possible that this is activated in response to a low redox potential in the chloroplast stroma.*



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(A) The process shown in the figure takes place in:

(a) Stroma (b) Stroma lamellae
(c) Grana (d) Matrix

(B) Which photosystem is involved in Cyclic photophosphorylation?

(a) PS I (b) PS II
(c) PS I and PS II (d) PS III

(C) Choose the correct option.

(a) The reaction centre is same in both, PS I and PS II.
(b) PS I is called P_{680}.
(c) Reaction centre is formed by xanthophyll.
(d) PS I is called P_{700}.

(D) Assimilatory power used in Cyclic photophosphorylation is:

(a) ATP (b) ADP
(c) NADP (d) NADPH

(E) Statement A: ATPs are used in Electron transport system.
Statement B: ATPs are passed on to the pigments of photosystem I from ETS.

(a) Statement A is incorrect.
(b) Statement B is incorrect.
(c) Both statements are incorrect.
(d) Both statements are correct.

Ans. (A) *(b) Stroma lamellae*

Explanation: Cyclic photophosphorylation occurs in stroma lamellae.

(B) *(a) PS I*

Explanation: Photosystem I is involved in cyclic photophosphorylation.

(C) *(d) PS I is called P_{700}.*

Explanation: Both PS I and PS II consist of different reaction centres. Maximum absorption in photosystem I takes place at 700 nm and therefore it is called P_{700}. Reaction centre is formed by a single molecule of chlorophyll *a*.

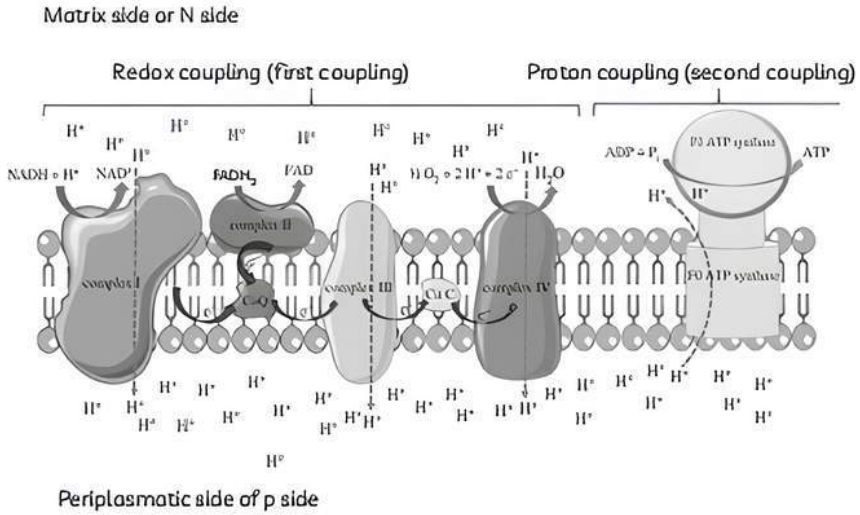
(D) *(a) ATP*

Explanation: The cyclic flow of electrons in cyclic photophosphorylation occurs due to photophosphorylation of Adenosine Diphosphate (ADP) to Adenosine Triphosphate (ATP).

(E) *(a) Statement A is incorrect.*

Explanation: ETS does not use any ATP, it only passes ATP to pigments of PS I.

21. *Understanding how biological systems convert and store energy is a primary purpose of basic research. However, despite Mitchell's chemiosmotic theory, we are far from the complete description of basic processes such as oxidative phosphorylation and photosynthesis. After more than half a century, the chemiosmotic theory may need updating, thanks to the latest structural data on respiratory chain complexes. In particular, up-to-date technologies, such as those using fluorescence indicators following proton displacements, have shown that proton translocation is lateral rather than transversal with respect to the coupling membrane. Furthermore, the definition of the physical species involved in the transfer (proton, hydronium ion or proton currents) is still an unresolved issue, even though the latest acquisitions support the idea that protonic currents, difficult to measure, are involved. Look at the figure given below:*



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(A) Where does the splitting of water molecules take place?

(B) What kind of potential gradient formed inside thylakoid membrane in the lumen of thylakoid?

(C) (i) Where does the low concentration of proton gradient form?

(ii) Plastoquinone acts as ..... .

Ans. (A) Splitting of water occurs on the inner side of the thylakoid membrane.

(B) High potential gradient is formed inside the thylakoid membrane in the lumen of thylakoid.

(C) (i) Low concentration of proton gradient is formed in the stroma, outer side of thylakoid membrane.

(ii) Plastoquinone acts as a Proton and electron carrier.

VERY SHORT ANSWER Type Questions (VSA)

[1 mark]

22. Which one of the photosystems can carry on photophosphorylation independently?

[Delhi Gov. QB 2022]

Ans. PS I can carry cyclic photophosphorylation independently.

23. Splitting of water produces which type of ions?

Ans. Electrons and hydrogen ions are produced due to the splitting of water.

Related Theory

➥ *Splitting of water provides new electrons to photosystem II. water molecules are splitted into three main components, namely, protons, electrons and oxygen, respectively. Protons from splitting of water are used as components of reaction that makes NADPH. Electrons formed in water splitting replace electrons that are lost in PS II. Oxygen formed is liberated into the atmosphere.*

24. Oxygen was invented in which year?

Ans. Oxygen was invented in 1774 by Joseph Priestley.

Caution

➥ *Students should remember that both the oxygen invention and series of experiments were carried out by Joseph Priestley in the 70's, but oxygen was invented in 1774 and series of experiments were performed in 1770.*

25. Which form of energy is used in photosynthesis?

Ans. The form of energy used in photosynthesis is solar energy.

SHORT ANSWER Type-I Questions (SA-I)

[2 marks]

26. Which type of wavelength (in nm) is called Photosynthetically Active Radiation (PAR)?

[NCERT Exemplar]

Ans. The light range between 400-700 nm of wavelength is called PAR (Photosynthetically Active Radiation). It is the amount of light available for photosynthesis. Photosynthetically Active Radiation varies as per the season and changes depending on the latitude and time of day.

27. What are the products of the photochemical phase?

Ans. Products of photochemical phase or light reaction are oxygen, ATP and NADPH. Photochemical phase takes place in the presence of light inside the thylakoid of the chloroplast. Wavelength required for the photochemical phase is 400 to 700 nm of visible light.

28. Where is photosystem II located? Mention its function.

Ans. Inner side of thylakoid membrane consists of photosystem II. PS II absorbs light with 680 nm and wavelength lower than 680 nm. It takes part only in non-cyclic photophosphorylation. The main functions of PS II are ATP synthesis and splitting of water. It is also represented as P_{680}.

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SHORT ANSWER Type-II Questions (SA-II)

[3 marks]

29. (A) Does moonlight support photosynthesis? Find out.

[Delhi Gov. QB 2022, NCERT Exemplar]

(B) What accessory photosynthetic pigments are found in most green plants?

Ans. (A) The intensity of moonlight is several thousand times less than that of direct sunlight, insufficient for the light-dependent phase of photosynthesis. So, photosynthesis does not occur in the moonlight.

(B) Excluding bacteria, all green plants have chlorophyll *a*. It carries out primary reactions of photosynthesis. Chlorophyll b, carotene and xanthophyll come under accessory pigments which absorb the different wavelength of light energy and transfer it to chlorophyll *a*, through spin resonance of electrons and prevent it from photo-oxidation.

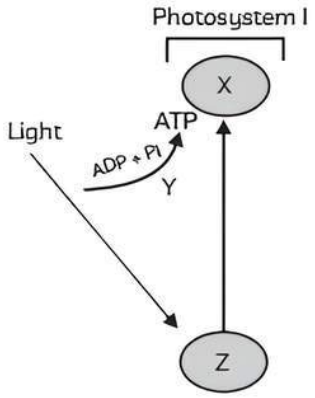
30. Explain in detail the cyclic flow of electrons in cyclic photophosphorylation.

Ans. Cyclic photophosphorylation is a process of photophosphorylation in which an electron thrown out of the excited photocenter is returned to it after passing through a number of electron carriers. Only photosystem I performs cyclic photophosphorylation. The electrons are circulated within the photosystem I and the phosphorylation take place due to the cyclic flow of electrons. The excited electrons do not pass on to NADP but are recycled to the PS I complex through the electron transport chain. The cyclic flow hence, results only in the synthesis of ATP and not NADPH + H^+.

31. Two potted plants were kept in an oxygen-free environment in transparent containers, one in total darkness and the other in sunlight. Which one of the two is likely to survive more? Justify your answer by giving the reason. [Delhi Gov. QB 2022]

Ans. The plant that is kept in natural sunlight will live longer. The plant which is kept in the dark is unable to perform photosynthesis, therefore, the container will quickly fill with carbon dioxide. The plant would die if there was insufficient oxygen in the container. The plant that is kept in light, on the other hand, will be able to perform photosynthesis and hence, they would be able to transform carbon dioxide into oxygen. As a result, this plant will live for a longer period of time.

32. (A) In the diagram shown below, identify the labelled (X), (Y) and (Z). What type of phosphorylation is possible in this?



(B) Give any two points of difference between cyclic and non-cyclic photophosphorylation.

[Delhi Gov. QB 2022]

Ans. (A) X– e^- acceptor

Y– Electron transport system

Z– Chlorophyll P_{700}

(B)

Cyclic Photophosphorylation	Non-cyclic Photophosphorylation
In this, the electrons move in a circular pattern.	The electron movement is non-cyclic.
It involves only photosystem (PS I).	It involves both photosystem I and II (PS I and PS II).
Photolysis of water does not occur.	Photolysis of water occurs.
P_{700} is the electron donor and the final electron acceptor.	P_{680} is the first electron donor and $NADP^+$ is the final electron acceptor.
Oxygen is not evolved.	Oxygen is evolved.
Cyclic photophosphorylation usually occurs at a low light intensity.	Non-cyclic photophosphorylation is favoured by high light intensity.
Photolysis of water does not take place.	Photolysis of water takes place.

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Only ATP is synthesised.	Both ATP and reduced coenzymes are synthesised.
It generally occurs at low light density.	It generally occurs at high light intensity.

Caution

It is to be noted that both cyclic and non-cyclic photophosphorylation are light-dependent reactions and produce ATP. The other similarities are

(1) They are both electron transport systems.

(2) In both cycles, ATP is produced.

(3) They both are involved in production of assimilatory powers.

(4) They are both dependent on light.

LONG ANSWER Type Questions (LA)

[4 & 5 marks]

33. Gaurav recently read about electron transport in his school's library. Explain in detail about electron transport.

[NCERT Exemplar]

Ans. The electron transport chain is a group of proteins that carry electrons across a membrane to create a gradient of protons, which produces ATP (Adenosine Triphosphate), which is required for cellular function in metabolic activities.

A proton gradient is formed throughout the process when protons are pushed from the mitochondrial matrix into the cell's intermembrane space, which also aids in ATP synthesis.

Because it relies on a higher concentration of protons to generate "proton motive force," the usage of a proton gradient is sometimes referred to as the chemiosmotic mechanism that drives ATP production.

The number of protons pumped across the inner mitochondrial membrane is exactly proportional to the amount of ATP produced. The electron transport chain is made up of a succession of redox processes in which electrons are transferred from a source molecule to an acceptor molecule *via* protein complexes.

The proton gradient is created as a result of these reactions, allowing mechanical work to be transformed into chemical energy and so ATP production. In eukaryotes, the complexes are embedded in the cristae, the inner mitochondrial membrane.

34. Garima and Sakshi studied light reaction and dark reaction respectively. Then they started discussing about each and decided to differentiate between them. Give the differences between the two as Garima and Sakshi.

Ans.

S. No.	Light reaction	Dark reaction
(1)	It is also known as photochemical phase.	It is also known as biochemical phase.
(2)	It is the first phase of photosynthesis.	It is the second phase of photo-synthesis.
(3)	Directly light driv-en.	Not directly light driven.
(4)	Produces ATP and NADPH.	Produces glucose by using ATP and NADPH.
(5)	Oxygen is liberat-ed in light reaction.	Dark reaction uses carbon diox-ide.
(6)	No fixation of carbon dioxide.	Fixation of carbon dioxide takes place.
(7)	It includes cyclic photophosphory-lation and non-cy-clic photophos-phorylation.	Dark reaction consists of Calvin cycle, CAM and C_4 pathway.
(8)	It is an energy har-vesting reaction.	It is a synthesis reaction.

35. Explain Non-cyclic photophosphorylation in detail.

Ans. Both PS I and PS II are involved in non-cyclic photophosphorylation. The electron transport chain begins with the release of electrons from PS II in this case.

In this chain, high-energy electrons emitted from PS II do not return to PS II but instead reach PS I, which then contributes to convert NADP to NADPH after passing *via* an electron transport chain.

In the dark reaction, the reduced NADP (NADPH) is used for carbon dioxide reduction. The oxidation of water molecules is caused by electron-deficient PS II.

Protons, electrons, and oxygen atoms are released as a result. PS II takes up electrons to return to a reduced state, while NADP accepts protons and oxygen is liberated.

Because high-energy electrons emitted from PS II do not return to PS II during this phase, the electron requirement is fulfilled by splitting of water, this process is called non-cyclic photophosphorylation.

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C_3 AND C_4 PLANTS 2

TOPIC 1

WHERE ARE THE ATP AND NADPH USED?

The product of light reaction ATP and NADPH are used to incorporate carbon from CO_2 into sugar. It occurs in the stroma of chloroplasts. This reaction is known as Dark reaction. The reaction itself does not require light but the process usually occurs in the light and continues for a short time after the plant is in dark as long as NADPH and ATP are there. For understanding of CO_2 fixation, Melvin Calvin identified the intermediate compounds and gave the detailed pathway of carbon in photosynthesis called Calvin cycle, in which he use the radioactive C^{14} in algal photosynthesis and finally discovered that the 3-carbon compound, *i.e.* 3 - phosphoglyceric acid was the first stable product of photosynthesis.

He also worked on that whether all plants formed the same 3-carbon compound or whether any other product formed in CO_2 fixation and after conducting experiments on a wide range of plants he found that again the first stable product is an organic acid but not 3-carbon atom compounds. But it was 4-carbon compound acid. This was oxaloacetic acid (OAA). Then he concluded that CO_2 assimilation during photosynthesis to be of two types:

(1) Those plants who formed their first stable product C_3 acid (PGA) in CO_2 fixation, *i.e.* C_3 pathway.

(2) Those who formed the first stable product C_4 acid (OAA) in CO_2 fixation, *i.e.* C_4 pathway.

The Primary Acceptor of CO_2

Since the PGA is a 3-carbon compound, it was thought that CO_2 was primarily accepted by a 2-carbon to form a 3-carbon PGA; they spent many years to identifying the 2-carbon compound in chloroplast. Then they further investigate and finally experimentally proved that CO_2 is primarily accepted by RuBP (Ribulose bisphosphate, 5-carbon compound) which produces two molecules of PGA.

The Calvin Cycle

Calvin and his colleagues investigated that some PGA is again transferred back to give RuBP to accept fresh CO_2 molecules and he operated it in a cyclic manner. This pathway occurs in all photosynthetic plants, whether they have C_3 or C_4 pathways. The Calvin cycle is divided into three distinct stages:

(1) **Carboxylation:** Carboxylation is the addition of carbon dioxide with RuBP to form a stable intermediate organic compound. This reaction is catalysed in the presence of enzyme RuBP carboxylase oxygenase (RuBisCO) which forms two molecules of 3-phosphoglyceric acid (PGA). This is the first stable product of photosynthesis.

(2) **Reduction:** In the reduction, there are a series of reactions to form glucose. First, the ATP is required to phosphorylate the PGA and give rise to phosphoglyceric acid. Then this ATP is converted to ADP and second, this phosphoglyceric acid is reduced by NADPH to produce phosphoglyceraldehyde. Six turns of the Calvin cycle are required to synthesise one molecule of glucose.

(3) **Regeneration:** In this step, regeneration of RuBP takes place by ATP phosphorylation to produce RuBP. It is a crucial step to continue the cycle.

So, for every CO_2 molecule entering the three molecules of ATP and two molecules of NADPH are required. The net reaction of C_3 dark fixation of carbon dioxide is:

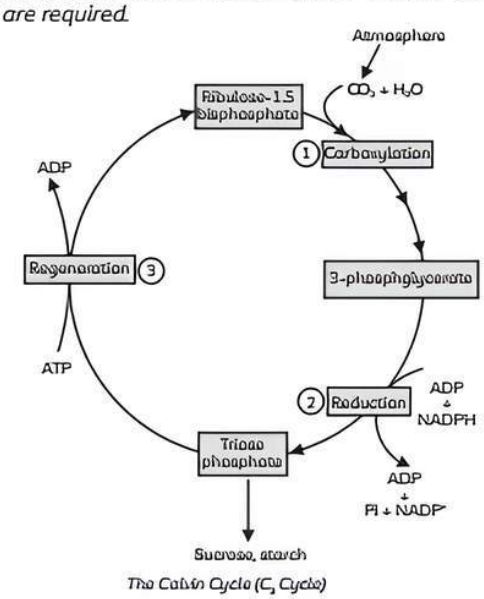
$$6RuBP + 6CO_2 + 18\ ATP + 12\ NADPH \rightarrow C_6H_{12}O_6 + 18\ ADP + 18Pi + 12\ NADP^+$$

In the Calvin cycle:

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

Important

➥ *To move one molecule of glucose, 6 turns of the Calvin cycle are required.*



The Calvin Cycle (C_3 Cycle)

Important

➥ *The Calvin cycle is also known as C_3 cycle as the 1st stabel compound of Calvin cycle is 3-carbon compound named 3-phosphoglyceric acid.*

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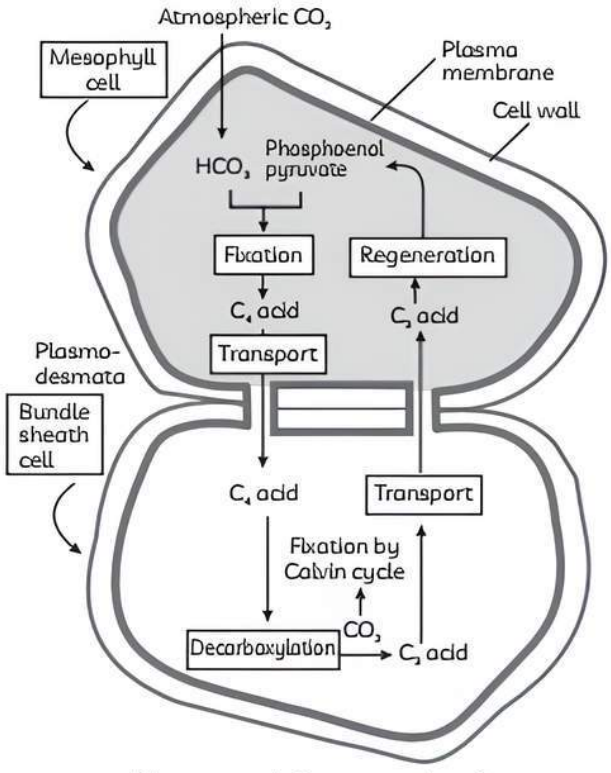
TOPIC 2

THE C_4 PATHWAY

The plants that perform C_4 cycle are found in tropical dry and hot regions. In this cycle, the first stable product of CO_2 fixation is oxaloacetic acid (OAA), a 4-carbon compound. These plants use O_3 pathway as the main biosynthetic pathway. These are different from C_3 plants because C_4 plants have a special leaf anatomy called Kranz anatomy, they tolerate high temperatures and respond to high intensities of light. In Kranz's anatomy of leaf, vascular bundles are surrounded by a layer of large size bundle sheath cells that contain large numbers of chloroplasts, no intercellular spaces, thick walls impervious to gasses and lack grana *i.e* their chloroplast is agranal type.

This pathway is also called the Hatch and Slack pathway. The processes include in the pathway are:

First, the carbon dioxide combines with 3-carbon molecules called phosphoenol pyruvate (PEP) in mesophyll cells in the presence of the enzyme PEP carboxylase. Then it is converted to 4-carbon compound called oxalo acetic, acid, then malic acid or aspartic acid which are transported to cells in a bundle sheath. In bundle sheath cells, the malic acid is decarboxylated to carbon dioxide and 3-carbon molecules. Then these 3-carbon molecules return to the mesophyll cell where it is converted to PEP. The carbon dioxide released in bundle sheath cells enters the C_3 cycle where these cells with the help of RuBisCO fix CO_2 to sugars. The Calvin pathway is common for both C_3 and C_4 plants.



Diagrammatic Representation of Hatch and Slack Pathway

Important

The C_4 Plants contain dimorphic chloroplasts, that means, chloroplasts in mesophyll cells are granal whereas in bundle sheath cells they are agranal.

Example 2.1: Case Based:

The leaves of C_4 plants require at least five ATP and two NADPH to fix one molecule of CO_2. Thus, the pathway requires a total 30 ATP and 12 NADPH molecules to synthesise one molecule of glucose. The C_4 plants can absorb CO_2 even from a much low CO_2 concentration when the C_3 plants fail to avail it. Thus, the C_4 plants can perform a high rate of photosynthesis even when the stomata are nearly closed. The C_4 cycle requires more light energy to fix CO_2 as compared to C_3 plants. They also maintain a high rate of photosynthesis under conditions of water shortage where the C_3 plants would stop photosynthesis. Thus, the C_4 plants are better adapted to tropical and desert areas where sunlight is more intense and the growing season is longer.

(A) In C_4 plants, synthesis of sugars or final CO_2 fixation occurs in:

- **(a) Undifferentiated mesophyll cells**
- **(b) Bundle sheath cells**
- **(c) Epidermal cells**
- **(d) Spongy cells**

(B) Which one of the following is an incorrect match?

- **(a) C_4 plants – Kranz anatomy.**
- **(b) First stable product of Calvin cycle – phosphoglyceric acid**
- **(c) First stable product of C_4 cycle – oxaloacetic acid**
- **(d) Maize - C_3 plant**

(C) Why Calvin cycle occurs in C_4 plants?

(D) Can you tell whether a plant is C_3 or C_4 by looking at a plant externally?

(E) Assertion (A): C_3 and C_4 cycles both can occur in the same plant.

Reason (R): C_3 cycle occurs in dicots and C_4 cycle occurs in monocots.

- **(a) Both A and R are true and R is the correct explanation of A.**
- **(b) Both A and R are true and R is not the correct explanation of A.**
- **(c) A is true but R is false.**
- **(d) A is false but R is true.**

Ans. **(A)** *(b) Bundle sheath cells*

Explanation: In C_4 plants, carbon dioxide fixation occurs inside the bundle sheath cell through the Calvin cycle. RuBP of the Calvin cycle is called secondary or final acceptor in C_4 plants whereas in mesophyll cells,

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CO_2 combines with PEP to form oxaloacetic acid. Spongy cells help in gaseous exchange during photosynthesis.

(B) *(d) Maize- C_3 plant.*

Explanation: All the options given above are correctly matched except Maize, which is a C_4 plant. Because it has special leaf anatomy called Kranz anatomy to tolerate high temperatures.

(C) Calvin cycle is the basic pathway for the synthesis of sugar (glucose or fructose). It occurs in all plants including C_4 plants and CAM plants.

(D) The plants which are adapted to dry tropical regions have the C_4 pathway. However, the C_4 plants do not show any characteristics in external morphology. Therefore, we can not say whether a plant is C_3 or C_4 by looking at it externally.

(E) *(c) A is true but R is false.*

Explanation: C_3 and C_4 cycles can occur in the same plant for example in maize and sugarcane both pathways occur. C_3 cycle occurs in 95% of all the plants on earth. So it is not specific for dicots. It occurs in both monocots and dicots whereas C_4 cycle occurs in fewer plants. It is an additional feature of some plants which acts as an adaptation to become more efficient and prevent photorespiration.

Table: Differences between C_3 and C_4 Plants

S. No.	C_3 Plants (Calvin Cycle)	C_4 Plants (Hatch-slack Cycle)
(1)	Ribulose bisphosphate is the first acceptor of CO_2.	Phosphoenolpyruvate is the first acceptor of CO_2, while ribulose bisphosphate is the second acceptor.
(2)	Phosphoglyceric acid is the first acceptor of CO_2.	Auto acetic acid is the first product.
(3)	CO_2 compensation point is 25-100 ppm.	CO_2 compensation point is 0-10 ppm.
(4)	Mesophyll cells perform complete photosynthesis.	Mesophyll cells perform only initial fixation.
(5)	In higher plants operating C_3 cycle, the chloroplasts are all granal.	There are two types of chloroplast, grana in mesophyll cells and agranal in bundle sheath cells.
(6)	The rate of carbon assimilation is low.	The rate of carbon assimilation is quite rapid.
(7)	At low temperature, C_3 plants are more efficient while at high temperature their photosynthetic activity is comperatively reduced.	C_4 plants are less efficient than C_3 plants at low temperature but they have a higher net assimilation at high temperature.
(8)	Fixation of one molecule of CO_2 uses 3 ATP and 2NADPH.	Fixation of one molecule of CO_2 requires 5 ATP and 2NADPH.
(9)	C_3 plants usually perform photosynthesis only when stomata are open.	C_4 plants perform photosynthesis even when stomata are closed.

Example 2.2: Case Based:

Photosynthetic reactions which are dependent on the products of light reactions are called biosynthetic phase or dark reactions. There are two main pathways – Calvin cycle and C_4 (dicarboxylic acid) cycle in which assimilatory power (ATP and NADPH) produced during photochemical phase is used in fixation and reduction of carbon dioxide.

The C_4 photosynthetic carbon cycle is an elaborated addition to the C_3 photosynthetic pathway. It evolved as an adaptation to high light intensities, high temperatures, and dryness. Therefore, C_4 plants dominate grassland floras and biomass production in the warmer climates of the tropical and subtropical regions.

(A) The special feature of C_4 plants is:

- **(a) They can tolerate high temperatures.**
- **(b) They have lesser productivity of biomass.**
- **(c) They show less response to light intensity.**
- **(d) All of the above.**

(B) Glucose synthesis occurs during which stage of C_3 cycle:

- **(a) Carboxylation** **(b) Regeneration**
- **(c) Reduction** **(d) None of these**

(C) Where does Calvin pathways do takes place in C_3 and C_4 plants?

(D) Where in the chloroplast does a dark reaction occur?

(E) Assertion (A): Light reaction occurs in thylakoids.

Reason (R): Dark reaction occurs in the stroma of chloroplasts.

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(a) **Both A and R are true and R is the correct explanation of A.**

(b) **Both A and R are true and R is not the correct explanation of A.**

(c) **A is true but R is false.**

(d) **A is false but R is true**

Ans. (A) *(a) They can tolerate high temperatures.*

Explanation: C_4 plants tend to close stomata to avoid loss of water, which increases photorespiration at high temperatures whereas C_4 plants are more productive and respond to high light intensities.

(B) *(c) Reduction*

Explanation: The glucose synthesis occurs in C_3 cycle in the reduction phase. Whereas in regeneration, some of G3P molecules are used to produce glucose while others are recycled to regenerate RuBP acceptor and Carboxylation in which a carboxylic acid is produced with the help of substrate and carbon dioxide.

(C) Calvin cycle takes place in mesophyll cells of C_3 plants and bundle sheath cells of C_4 plants.

(D) The part of chloroplast where the dark reaction takes place is Stroma.

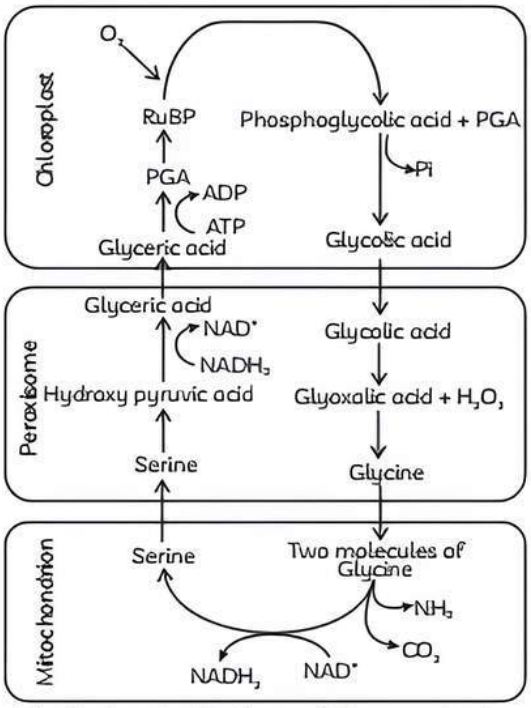
(E) *(b) Both A and R are true and R is not the correct explanation of A.*

Explanation: Both statements are correct. The process of photosynthesis occurs in two steps: light and dark reactions. Light reaction is also called photochemical phase and occurs in thylakoids and dark reaction is called thermochemical phase and occurs in the stroma of chloroplasts.

TOPIC 3

PHOTORESPIRATION

The photorespiration is the light-dependent process of oxygenation of RuBP. During photorespiration, RuBisCO shows oxygenation activity. It shows important difference between C_3 plants and C_4 plants. In the first step of the Calvin cycle, the RuBP combines with carbon dioxide to form PGA in the presence of enzyme RuBisCO. RuBisCO is the active site for both carboxylation and oxygenation but has more affinity for carbon dioxide as compared to oxygen and it is related to concentration of O_2 and CO_2 which determines the binding state of the enzyme.



The Biochemical Pathway of Photorespiration

In C_3 plants, some O_2 will bind to RuBisCO it occurs when CO_2 concentration is low. RuBP oxygenase instead of fixing carbon dioxide oxidises RuBP to produce PGA and 2-carbon atom phosphoglycolate. This pathway is called photorespiration. There is neither synthesis of sugar nor ATP as well as no synthesis of NADPH whereas C_4 plants are exception, in this, the enzyme is located at bundle sheath cells where the concentration of CO_2 is high due to C_4 acid decarboxylate and releases CO_2. Thus the RuBisCO is purely carboxylase in nature in C_4 plants and they have a high tolerance to temperature. Thus they show high productivity.

The site for photorespiration is chloroplast, peroxisome and mitochondria. It was discovered by Dicker and Tio (1959) in Tabacco Plant.

Example 2.3: RuBisCO is an enzyme that acts as both a Carboxylase and oxygenase. Why do you think the RuBisCO carries out more carboxylation in C_4 plants? [NCERT]

Ans. RuBisCO is an enzyme which is found abundantly on the earth which plays a major role in the first major step of atmospheric carbon fixation. It is Ribulose-1, 5-bisphosphate carboxylase. It acts as both carboxylase and oxygenase. In C_3 plants, this enzyme is present in mesophyll leaves where it catalyses carboxylation whereas in C_4 plants, it is present in bundle sheath cells with another enzyme called PEP and catalysed carboxylation reaction during photosynthesis. RuBisCO carries out more carboxylation in C_4 plants because these plants have a mechanism that increases the concentration of CO_2 at the

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enzyme site. During the C_4 pathway, when the C_4 acid from the mesophyll cells is broken down in the bundle sheath cells, it releases CO_2. This results in increasing the intracellular concentration of CO_2. So, RuBisCO functions as a carboxylase and binds with plants and carries out more carboxylation.

TOPIC 4

FACTORS AFFECTING PHOTOSYNTHESIS

The rate of photosynthesis is very important for determining productivity. It is affected by several factors, both internal and external. The internal factors include the size, number, age and orientation of leaves, mesophyll cell and chloroplast and internal CO_2 concentration whereas the external factor includes the availability of sunlight, temperature, CO_2 concentration and water. So these several factors interact and affect photosynthesis, when several factors affect any biochemical process then the Law of limiting factors comes.

Blackman's law of limiting factor

It states that 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.

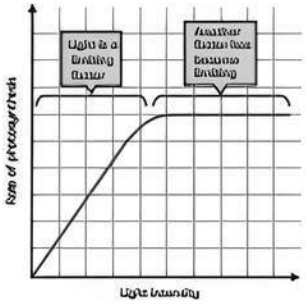
Light

The main source of light for green plants for photosynthesis is solar radiation. Light varies in quality of light, intensity and duration of exposure of light. There is a linear relationship between incident light and carbon dioxide fixation.

Under low intensity, the rate of photosynthesis is low whereas at high intensity, the rate of photosynthesis also increases. The light intensity at which the rate of photosynthesis and rate of respiration is equal is called light compensation point.

As the light intensity increases, the rate of photosynthesis increases.

The light intensity at which a plant can achieve maximum amount of photosynthesis is called light saturation point. Beyond the saturation point, the rate of photosynthesis begins to decline. But it is important to note that light is rarely a limiting factor in nature except for plants in shade or dense forests. Because light saturation occurs at 10% of the total sunlight.



Graph of light intensity and rate of photosynthesis

Carbon Dioxide Concentration

It is the major limiting factor for photosynthesis as their concentration is low in nature (0.03 to 0.04 per cent). If its concentration increases upto 0.05%, the rate of photosynthesis also increases. The C_3 and C_4 plants respond differently to CO_2 concentration.

When CO_2 concentration is reduced, there comes a point at which plant parts stop absorbing carbon dioxide from their environment. It is called CO_2 compensation point or threshold value. At this value, CO_2 fixed during photosynthesis is equal to CO_2 evolved in respiration and photorespiration. The value is 25-100 ppm for CO_3 plants and 0-10 ppm for C4 plants. The optimum CO_2 concentration for C_4 plants is 360 ppm and more than 450 ppm for C_3 plants. This is called saturation point. The tomato and bell pepper plants are allowed to grow in CO_2 rich atmosphere for high productivity.

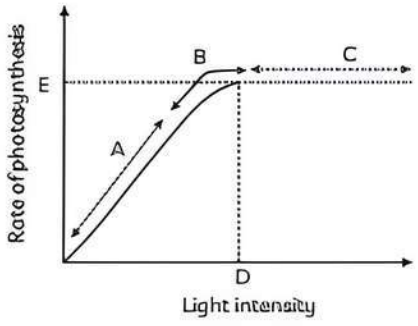
Temperature

The dark reactions are temperature controlled as enzymes deactivate at high temperatures. The requirement of temperatures varies with the plants for optimum photosynthesis like C_4 plants respond to high temperatures whereas the C_3 plants to low temperature. The temperature for photosynthesis also depends upon the habitat of plants. The optimum temperature for C_3 plants is 10-25 degree Celsius while for C_4 plants it is 30 - 45 degree Celsius. At this temperature range, both C_3 and C_4 plants show maximum photosynthesis.

Water

Water is the most important material for photosynthesis. If the water supply is affected then the rate of photosynthesis also decreases as the stomata remain close in water stress conditions and this also makes leaves wilt.

Example 2.4: The figure shows the effect of light on the rate of photosynthesis. Based on the graph, answer the following questions:



Graph showing effect of light intensity on the rate of photosynthesis

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(A) **At which points (A, B or C) in the curve is light a limiting factor?**

(B) **What could be the limiting factors in region A?**

(C) **What do C and D represent on the curve?**

[NCERT]

Ans. (A) Light is a limiting factor at A and 50% of B which is due to the increase in the photosynthetic rate with an increase in the intensity of light.

(B) Light could be a limiting factor.

(C) C represents the rate of photosynthesis that is not increased by increasing light intensity because some other factors may be limiting. D represents the intensity of light at which some other factor became limiting.

OBJECTIVE Type Questions

[1 mark]

Multiple Choice Questions

1. In light reaction, which of the following molecules are produced?

(a) ATP **(b) NADPH**

(c) ATP and NADPH **(d) None of these**

Ans. *(c) ATP and NADPH*

Explanation: During the light reaction, the energy is absorbed from sunlight and converted into chemical energy by breaking down water. It is the first process of photosynthesis and produces ATP and NADPH.

2. C_4 plants show high productivity because:

(a) they have no photorespiration

(b) they have Kranz anatomy

(c) they have PEP

(d) none of the above

Ans. *(a) they have no photorespiration*

Explanation: Photorespiration is absent in C_4 plants due to which they have high productivity as in C_3 plants. photorespiration is a wasteful and energy consuming process in which 25% of fixed carbon dioxide lose. Due to which, there is a decrease in the photosynthetic productivity in C_3 plants whereas Kranz anatomy in C_4 plants provides a site for carbon dioxide fixation and PEP helps to form oxaloacetate.

3. First CO_2 acceptor in C_3 plants:

(a) Phosphoglyceric acid

(b) Ribulose bisphosphate

(c) Oxaloacetate

(d) All of the above **[Diksha]**

Ans. *(b) Ribulose bisphosphate*

Explanation: In photosynthesis of C_3 plants, the Ribulose bisphosphate is a primary acceptor of CO_2 fixation and helps in the formation of sugar whereas phosphoglyceric acid and oxaloacetate are the first stable product of photorespiration and C_4 pathway, respectively.

Related Theory

➥ *Ribulose bisphosphate is an enzyme which acts as both carboxylase and oxygenase. It is the most abundant protein in the atmosphere. It is located on the thylakoid membrane and enhances the production of plants.*

4. How C_4 plants are different from C_3 plants?

(a) Consumed number of ATP molecules

(b) Type of first stable product

(c) Substrate that accepts carbon dioxide

(d) All of the above

Ans. *(d) All of the above*

Explanation: As first stable product is different in both cases as well the substrate which accepts carbon dioxide is also different in both plants and the ATP molecule consumed by both plants is different.

Related Theory

➥ ***C_4 cycle:*** *A total number of ATPs required for the fixation of six carbon dioxide molecules during photosynthesis are 30 ATPs.*

C_3 cycle: *In this only 18 ATPs are required for the fixation of 6 carbon dioxide molecules.*

5. Where malic acid is formed in plants?

(a) Mesophyll cells **(b) Epidermis**

(c) Phloem **(d) Bundle sheath cells**

Ans. *(a) Mesophyll cells*

Explanation: The first stage of fixation of carbon dioxide takes place in mesophyll cells where CO_2 combines with an acceptor to form oxaloacetic acid and then is reduced to malic acid and this malic acid is then transported to bundle sheath. On the other hand, phloem is used for the conduction of organic food materials in plants and epidermis provides protection to the plants.

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6. **How many turns of the Calvin cycle produce one molecule of hexose?**

(a) Two **(b) Six**

(c) Four **(d) Eight**

Ans. *(b) Six*

Explanation: In the Calvin cycle, one turn fixes the one carbon atom and to fix the glucose (hexose) sugar six carbon atoms are required. Thus, the Calvin cycle requires six turns.

Caution

Students tend to miss the point that Calvin cycle occurs in all plants including CAM plants.

7. **C_4 cycle is also known as:**

(a) EMP pathway

(b) TCA cycle

(c) Hatch and Slack pathway

(d) None of the above

Ans. *(c) Hatch and Slack pathway*

Explanation: C_4 pathway was given by M.D. Hatch and Roger Slack. Thus named as Hatch and Slack pathway whereas EMP pathway is also known as glycolysis and TCA cycle is also called Kreb's cycle.

8. **The enzyme that fixes carbon dioxide in C_3 plants is:**

(a) RuBisCO **(b) PEP Carboxylase**

(c) Hydrogenase **(d) All of the above**

Ans. *(a) RuBisCO*

Explanation: RuBisCO fixes atmospheric carbon dioxide in C_3 plants while PEP carboxylase is used in CAM plants to fix carbon dioxide at night and hydrogenase helps in conversion of hydrogen molecules to protons which shows hydrolytic splitting.

9. **When CO_2 is added to PEP, the first stable product synthesised is:**

(a) Pyruvate

(b) Glyceraldehyde-3-phosphate

(c) Phosphoglycerate

(d) Oxaloacetate **[NCERT Exemplar]**

Ans. *(d) Oxaloacetate*

Explanation: In plants, the first step in fixation of carbon dioxide occurs in mesophyll cells where it combines with phosphoenol pyruvate to form oxaloacetate. Whereas pyruvate, PGA and Glyceraldehyde. 3-phosphate is the product formed in the Calvin cycle.

10. **The reaction that is responsible for the primary fixation of CO_2 is catalysed by:**

(a) RuBP carboxylase

(b) PEP carboxylase

(c) RuBP carboxylase and PEP carboxylase

(d) PGA synthase **[NCERT Exemplar]**

Ans. *(c) RuBP carboxylase and PEP carboxylase*

Explanation: RuBP carboxylase and PEP carboxylase are responsible for carbon dioxide fixation in C_3 and C_4 plants respectively.

11. **The first product in photorespiration in C_3 plants is:**

(a) Phosphoglycerate and phosphoglycolate

(b) OAA

(c) Pyruvate

(d) None of the above

Ans. *(a) Phosphoglycerate and phosphoglycolate.*

Explanation: In photorespiration in C_3 plants, the first stable products are Phosphoglycerate and phosphoglycolate. They are formed by splitting of intermediate unstable compounds produced by carbon dioxide and RuBP in the presence of water whereas OAA is the product of C_4 cycle and Pyruvate is the product of Calvin cycle.

12. **Law of limiting factor was proposed by:**

(a) Hill **(b) Blackman**

(c) Von mayer **(d) Arnon** **[Diksha]**

Ans. *(b) Blackman*

Explanation: Blackman proposed the law of limiting factor in 1905. Hill gave Hill's reaction and proposed the Z-scheme of phosphorylation. Arnon said that ferredoxin is a universal part of photosynthetic apparatus.

Assertion-Reason (A-R)

Given below are two statements labelled as Assertion (A) and Reason (R). Select the most appropriate answer from the options given below:

(a) Both A and R are true and R is the correct explanation of A.

(b) Both A and R are true and R is not the correct explanation of A.

(c) A is true but R is false.

(d) A is false but R is true.

13. **Assertion (A): Photorespiration is not present in C_4 plants.**

Reason (R): Presence of high concentration of carbon dioxide in mesophyll cells.

Ans. *(a) Both A and R are true and R is the correct explanation of A.*

Explanation: In C_4 plants, there is Kranz's anatomy. The malic acid is broken down to release carbon dioxide in the bundle sheath cells due to which the concentration of carbon

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dioxide increases in the cells where the enzyme RuBisCO functions as carboxylase instead of oxygenase.

14. **Assertion (A):** **C_4 plants are adapted to tropical dry climates.**

Reason (R): **C_4 plants have a large number of chloroplast and thick walls which are impervious to gaseous exchange.**

Ans. *(a) Both A and R are true and R is the correct explanation of A.*

Explanation: C_4 plants have special anatomy of leaf *i.e.* Kranz anatomy in which there are large numbers of chloroplast, thick walls which are impervious to gaseous exchange and no extracellular spaces. Due to this specialized mechanism of photosynthesis, productivity increases. It helps them to survive in dry tropical and desert regions.

15. **Assertion (A):** **Six molecules of CO_2, 12 molecules of NADPH and 18 ATP are required to form one molecule of glucose.**

Reason (R): **Dark reaction produces ATP and NADPH.**

Ans. *(c) A is true but R is false.*

Explanation: In the Calvin cycle, the product glucose is formed by six molecules of carbon dioxide, 12 molecules of NADPH and 18 ATP. The net reaction of C_3 dark fixation of carbon dioxide is:

$$6CO_2 + 18\ ATP + 12\ NADPH \rightarrow C_6H_{12}O_6 + 18\ ADP + 12\ NADP$$

The dark reaction is not responsible for formation of ATP and NADPH. In dark reactions, there is the production of carbohydrates with the help of these assimilatory power.

16. **Assertion (A):** **RuBisCO also acts as an oxygenase.**

Reason (R): **Under high oxygen concentration and at high temperatures, the enzyme oxidises RuBP into 3-carbon phosphoglyceric acid and 2-carbon phosphoglycolate.**

Ans. *(a) Both A and R are true and R is the correct explanation of A.*

Explanation: RuBisCO acts as both carboxylase and oxygenase. When there is a high concentration of oxygen, this enzyme catalyzes the reaction and forms one molecule of phosphoglycolic acid and one molecule of phosphoglyceric acid but this does not happen in plants.

CASE BASED Questions (CBQs)

[**4** & **5** marks]

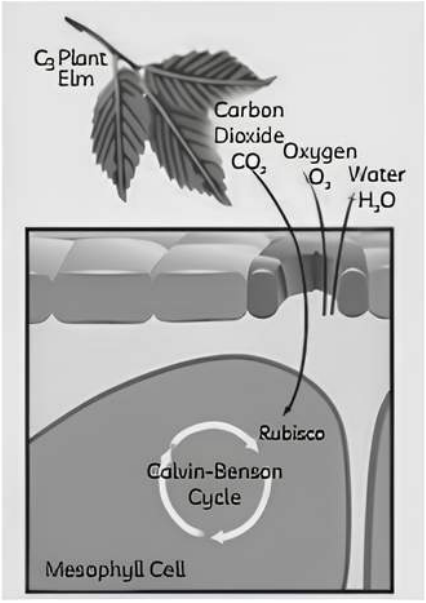
Read the following passages and answer the questions that follow:

17. *Photosynthesis is the process that plants use to turn light, carbon dioxide, and water into sugars that fuel plant growth, using the primary photosynthetic enzyme Rubisco.*

The majority of plant species on Earth uses C_3 photosynthesis, in which the first carbon compound produced contains three carbon atoms.

C_3 plants do not have the anatomic structure (no bundle sheath cells) nor the abundance of PEP carboxylase to avoid photorespiration like C_4 plants. One focus of the RIPE project is to create a more efficient pathway for photorespiration to improve the productivity of C_3 crops.

The RIPE project is working to improve photosynthesis in C_3 crops to ensure greater food security under future climate scenarios. C_3 plants are limited by carbon dioxide and may benefit from increasing levels of atmospheric carbon dioxide resulting from the climate crisis. However, this benefit may be offset by a simultaneous increase in temperature that may cause stomatal stress.



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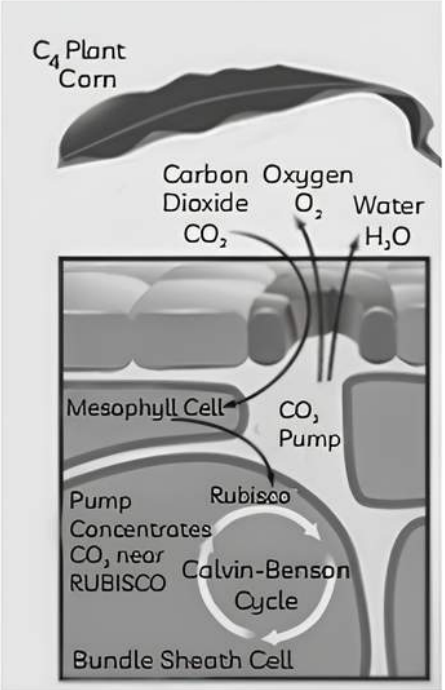

(A) What is the first stable product in this pathway?

(B) Where do photosynthetic functions take place in this pathway?

(C) (i) How many times the carbon dioxide fixation occurs in this cycle? Name the enzymes used to fix carbon dioxide in this pathway.

(ii) Name any two C_4 plants.

Ans. (A) Oxaloacetate.

(B) Mesophyll cells and bundle sheath cells.

(C) (i) Two times. PEP carboxylase and RuBisCO.

(ii) Sugar cane and maize.

18. *Photosynthesis occurs in two phases- light reaction (photochemical phase) and dark reaction. In dark reactions where products of light reactions are used to incorporate carbon from carbon dioxide to carbohydrates. The reaction does not require light. It takes place in the stroma of chloroplasts. There are two main pathways of this phase, Calvin cycle and C_4 cycle. The assimilatory power is generated in thylakoids and used in the synthesis of carbohydrates in the dark reaction. Light reaction of photosynthesis involves the participation of two separate pigment systems or photosystems, i.e. PS I and PS II.*

(A) Photosynthesis is a process in which:

(a) Carbon dioxide is reduced to carbohydrates.

(b) NADH is reduced to NAD.

(c) ATP is generated.

(d) None of the above

(B) In photosynthesis, the light reaction occurs in:

(a) Thylakoids (b) Fret channel

(c) Stroma (d) All of these

(C) During light reaction, the molecules formed are:

(a) C_4 acid (b) ATP and NADPH

(c) C_3 acid (d) None of these

(D) Dark reactions occur in:

(a) only in light

(b) only in the absence of light

(c) independent of light

(d) all of the above

(E) Assertion (A): When a molecule of chlorophyll *b* absorbs light it sends its energy to a molecule of chlorophyll *a*.

Reason (R): Chlorophyll *b* absorbs light of similar wavelengths which cannot be directly used for photosynthesis.

(a) Both A and R are true and R is the correct explanation of A.

(b) Both A and R are true and R is not the correct explanation of A.

(c) A is true but R is false.

(d) A is false but R is true.

Ans. (A) *(a) Carbon dioxide is reduced to carbohydrates.*

Explanation: During photosynthesis, the carbon dioxide is reduced to glucose and water is oxidized and NAD is reduced to NADH due to which ATP is not generated.

(B) *(a) Thylakoids*

Explanation: Light reaction occurs in the thylakoid membrane whereas the dark reaction occurs in the stroma of chloroplast.

Caution

Fret channels are found in chloroplast but it is not the exact site of light reaction.

(C) *(b) ATP and NADPH*

Explanation: Light reaction is the process in which the generation of energy rich molecules such as ATP and NADPH occurs. These are also known as assimilatory powers.

(D) *(c) Independent of light*

Explanation: Dark reaction is also called light-independent reaction. It does not require light and occurs in the stroma of chloroplasts where the products of light reaction (ATP and NADPH) are used to incorporate carbon from carbon dioxide to carbohydrate.

(E) *(c) A is true but R is false.*

Explanation: When a chlorophyll *b* molecule absorbs light, it transfers its energy to a chlorophyll *a* molecule. Chlorophyll *b* absorbs light at various wavelengths that cannot be used for photosynthesis directly.

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VERY SHORT ANSWER Type Questions (VSA)

[1 mark]

19. Name the internal factors that affect Photosynthesis.

Ans. Chlorophyll content, size, age and orientation of leaves, number and distribution of stomata, thickness of epidermis and cuticle, *etc.*

Related Theory

The transformation of photon energy into chemical energy by green parts of the plant is called photosynthesis.

20. How temperature affects the rate of photosynthesis?

Ans. The rate of photosynthesis increases by increasing temperature upto the optimum temperature. If the temperature decreases to its optimum value, then the rate of photosynthesis also decreases.

21. Which compound gives hydrogen to sugar in the Calvin cycle?

Ans. NADPH.

22. In which plants, RuBisCO is absent in mesophyll cells of chloroplast?

Ans. In C_4 plants.

23. Which cycle requires less energy to synthesize one molecule of glucose?

Ans. C_3 cycle requires less energy, *i.e.* 18 ATP whereas the cycle requires 30 ATP.

SHORT ANSWER Type-I Questions (SA-I)

[2 marks]

24. Do reactions of photosynthesis called 'Dark Reaction' need light? Explain. **[NCERT Exemplar]**

Ans. ATP and NADPH are used for the synthesis of food, *i.e.* sugars. It is also called the biosynthetic phase or dark reaction of photosynthesis. This does not directly depend on the presence of light but is dependent on the products of the light reaction.

25. Six turns of the Calvin cycle are required to generate one mole of glucose. Explain.

Ans. For one molecule of glucose to be removed from the pathway, six molecules of CO_2 must be fixed and the cycle must be turned six times. As a result, 3 ATP and 2 NADPH molecules are required for every CO_2 molecule entering the Calvin cycle. Six rotations of the cycle are needed to generate one molecule of glucose.

In	Out
Six CO_2	One Glucose
18 ATP	18 ADP
12 NADPH	12 NADP

26. Regeneration during the Calvin cycle requires 3 ATP molecules. True or false?

Ans. False.

Regeneration is the third and final step of the Calvin cycle. In this step, the CO_2 acceptor molecule RuBP is regenerated. Regeneration requires 1 ATP molecule for the purpose of phosphorylation.

27. Give the difference between Carboxylation and Oxygenation.

Ans.

S. No.	Carboxylation	Oxygenation
(1)	It brings about assimilation of CO_2.	It releases CO_2.
(2)	Oxygen is released.	Oxygen is consumed.
(3)	It is an anabolic process and performs photosynthesis.	It is a catabolic process and performs photorespiration.
(4)	It stores energy and occurs inside chloroplasts.	It wastes energy and occurs in chloroplast and peroxisomes.

28. Why do green plants start evolving carbon dioxide instead of oxygen on a hot sunny day? **[Delhi Gov. QB 2022]**

Ans. On a hot sunny day, enzyme RuBP carboxylase becomes active and its affinity for CO_2 decreases and for O_2 increases. Consequently more and more photosynthetically fixed carbon is lost by photorespiration.

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29. **Fill in the space, left blank in the given table to bring the difference between C_3 and C_4 plants:**

S. No.	Charac-teristics	C_3 plants	C_4 plants
(1)	Cell type	mesophyll	__ (A) .... and mesophyll phosphoenol
(2)	CO_2 acceptor	__ (B) __	pyruvate (PEP)
(3)	First CO_2 fixation product	3-PGA	__ (C) __
(4)	Optimum tempera-ture	__ (D) __	30° C to 45° C

[Delhi Gov. QB 2022]

Ans. (A) Bundle sheath

(B) RuBP

(C) OAA (oxaloacetic acid)

(D) 20°C-25°C

30. **RuBisCO is a dual enzyme. Justify the statement and explain the nature of enzyme showing its characteristics under different conditions.** **[Diksha]**

Ans. RuBisCO or Ribulose bisphosphate carboxylase oxygenase acts both as a CO_2 as well as O_2 acceptor. It has more affinity for CO_2 as compared to oxygen. So in C_3 plants, it acts as a carboxylase (CO_2 acceptor). At high temperatures, concentration of dissolved CO_2 in equilibrium with air decreases more than the concentration of O_2. Then it favours oxygenation.

SHORT ANSWER Type-II Questions (SA-II)

[**3** marks]

31. **(A) What is Photorespiration? Which plants show Photorespiration?**

(B) What steps are common in C_3 and C_4 photosynthesis?

Ans. (A) Photorespiration is a light-dependent process of oxygenation. RuBP and release of CO_2 by the photosynthetic organs of a plant. It is initiated in chloroplast and happens in the condition of high light intensity, reduced carbon dioxide levels and raised oxygen levels. C_3 plants carry out photorespiration.

(B) The steps which are common in C_3 and C_4 photosynthesis are:

(1) Photolysis of water in light reaction.

(2) Dark reaction occurs in stroma region

(3) Calvin cycle results in the formation of sugar

(4) Both undergo a phase of carboxylation and regeneration of RUBP in a dark reaction.

LONG ANSWER Type Questions (LA)

[**4** & **5** marks]

32. **Hatch and Slack pathway is a complex process which occurs in desert plants. Explain.**

Ans. Plants found in tropical hot and desert regions show C_4 pathway. In plants, the initial fixation of carbon dioxide occurs in mesophyll cells. The primary acceptor of this is phosphoenol pyruvate (PEP). It combines with CO_2 in the presence of PEP carboxylase to form oxaloacetate. Then, this OAA is reduced to malic acid and then this malic acid is transported to bundle sheath cells where they decarboxylated to form pyruvate and CO_2 and now final fixation takes place in bundle sheath through Calvin cycle. RUBP of the Calvin cycle is final acceptor in C_4 plants. Pyruvate and PEP formed in bundle sheath are sent back to mesophyll cells where it changes to phosphoenol pyruvate and energy is required for the same.

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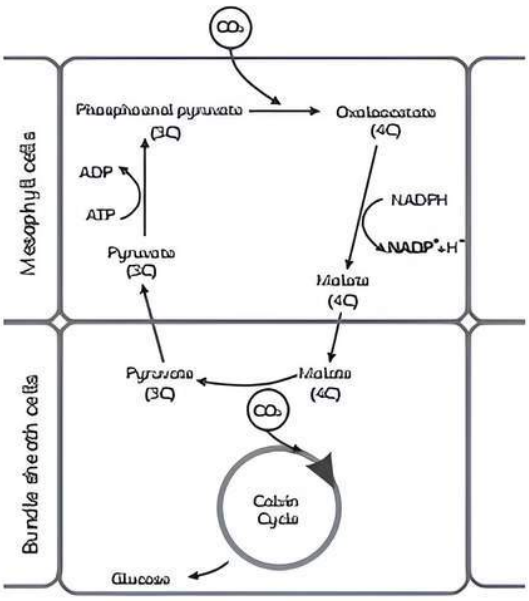

Hatch and Slack Pathway

Caution

Students must understand that Calvin pathway is a common pathway in both C_3 and C_4 plants, but it takes place only in mesophyll cells of C_3 plants but not in the C_4 plants.

33. State Blackman's law of limiting factors. Explain taking any three factors that affect photosynthesis. [Diksha]

Ans. Blackman's limiting factor states that when a process is conditioned as to its rapidity by a number of several factors, the rate of the process is limited by the pace of the slowest factor. It means the rate of a physiological process is limited at a given time by one and only one factor which is deficient.

The factors which affect the photosynthesis are:

(1) **Light:** The main source of light in green plants for photosynthesis is solar radiation. Light varies in quality of light, intensity and duration of exposure of light. There is a linear relationship between incident light and carbon dioxide fixation rates at low light intensities. At higher light intensities, gradually the rate of photosynthesis does not increase further as some other factor becomes limiting. More increase in incident light intensities will also cause a decrease in photosynthesis as they break the chlorophyll.

(2) **Carbon dioxide concentration:** It acts as a major limiting factor for photosynthesis as its concentration is low in nature, thus if we increase the amount of CO_2 then the rate of photosynthesis also increases. In C_3 plants if CO_2 concentration is high and the rate of photosynthesis also increases. The tomato and bell pepper plants are allowed to grow in CO_2 rich atmosphere for high productivity.

(3) **Temperature:** The dark reactions are temperature controlled as enzymes deactivate at high temperatures. The requirement of temperature varies with the plants for optimum Photosynthesis like C_4 plants respond to high temperatures whereas the C_3 plants to low temperatures. The temperature for photosynthesis also depends upon the habitat of plants.

34. Give reason:

(A) Calvin cycle occurs in mesophyll cells of C_4 plants.

(B) Photorespiration is considered as a wasteful process.

(C) Chloroplasts are generally located at the outer margins of mesophyll cells.

Ans. (A) In C_4 plants, the photosynthesis takes place in a thin-walled mesophyll cell and a 4-carbon acid is handed off to a thick-walled bundle sheath cell, where the Calvin cycle occurs in a chloroplast of that second cell. This protects the Calvin cycle from the effects of photorespiration.

(B) Photorespiration is considered as a highly wasteful process because it does not produce energy. On the other hand, it consumes energy and loses some amount of fixed CO_2. There is a 25% loss in C_3 plants. It does not occur in C_4 plants.

Caution

Students need to remember that Photorespiration is stimulated by : (i) high light intensities (ii) high oxygen concentration (iii) low carbon dioxide concentration (iv) high temperature.

(C) Chloroplasts are generally found in the margins of mesophyll cells which helps in easy diffusion of gases required for photosynthesis from the atmosphere to the inside of chloroplasts.

35. The entire process of photosynthesis consists of a number of reactions. Where in the cell does each of these take place?

(A) Synthesis of ATP and NADPH

(B) Photolysis of water

(C) Fixation of CO_2

(D) Synthesis of sugar molecule

(E) Synthesis of starch

Ans. (A) **Synthesis of ATP and NADPH:** Membrane system (Grana).

(B) **Photolysis of water:** Inner side of the membrane of thylakoid.

(C) **Fixation of CO_2:** Stroma of chloroplast.

(D) **Synthesis of sugar molecule:** Stroma of chloroplast.

(E) **Synthesis of starch:** Stroma of chloroplast.

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