

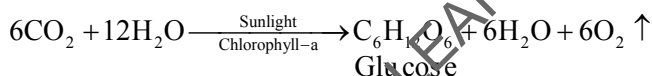
6.

Photosynthesis

6.0 : Introduction

Q.1. Define photosynthesis. Why is it a redox reaction ?

Ans: Photosynthesis (photon-light; synthesis-putting together) is an intracellular anabolic process in which glucose is synthesized from simple inorganic materials like CO_2 and water in the presence of light and chlorophyll with the evolution of oxygen as a by-product.
The overall equation of photosynthesis is



Photosynthesis as a redox reaction :

- Photosynthesis is considered as a redox reaction as it involves both reduction and oxidation reactions.
- Water is oxidized by the removal of H^+ while CO_2 is reduced by the addition of H^+ .
- The redox reactions of photosynthesis are necessary for the conversion of light energy into chemical energy.

Q.2. Why is photosynthesis called an anabolic process ?

- Ans.**
- Photosynthesis is the process by which solar energy is trapped by autotrophic organisms and converted into food for rest of the organisms.
 - Plants use simple inorganic materials and build these up into complex organic molecules. This is called **autotrophic nutrition or autotrophism** (auto = self, trophism = feeding).
 - In photosynthesis, carbohydrates are synthesized by utilizing the light energy. Thus, it is called **anabolic process** or energy building process and a mode of autotrophic nutrition.

Q.3. What are Chemoautotrophs? Give example.

Ans: Organisms which prepare their food by chemosynthesis, i.e. they use energy released during chemical reactions for synthesis of food are called as **Chemoautotrophs**. e.g. Bacteria such as nitrifying bacteria (*Nitrosomonas*), sulphur bacteria (*Thiobacillus*) and iron bacteria (*Ferrobacillus*) are chemosynthetic autotrophs.

Q.4. Why is photosynthesis called an endergonic process ?

Ans: A chemical reaction that requires the absorption of energy is called endergonic reaction. Sunlight provides necessary energy to plants for production of sugars during photosynthesis. Hence, it is an endergonic process.

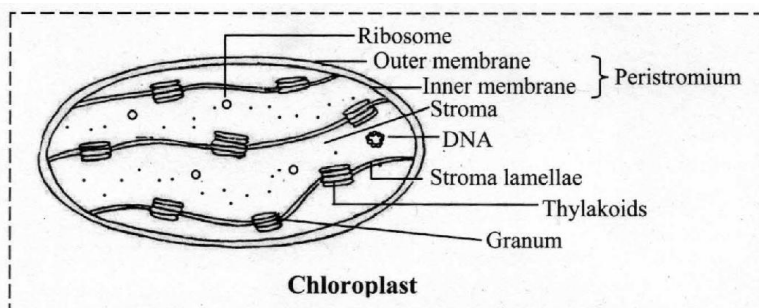
Q.5. What are Photosynthetic autotrophs (Photoautotrophs)? Give examples.

Ans: The organisms which prepare their own food by using light energy (solar energy) are called photosynthetic autotrophs or photoautotrophs. e.g. All green plants, protists like *Diatoms* and *Dinoflagellates*, prokaryotes like Cyanobacteria and green sulphur bacteria (*Chlorobium*)

6.1 : Site of Photosynthesis

Q.6. Describe the ultrastructure of chloroplast.

Ans:



Ultrastructure of chloroplast :

- i) Chloroplast are oval or elliptical in shape having a length of 4 to 10 microns and breadth of 2 to 3 microns.
- ii) It shows a double layered lipoprotein membrane (outer membrane and inner membrane together called Peristromium). It is about 40 - 60 Å in thickness.
- iii) The space in between these membranes is called **periplastidial space** or intraenvelop space.
- iv) The internal space is filled with a colourless, dense matrix called **Stroma**. It consists of lipids, proteins, DNA, RNA, enzymes and 70S ribosome.
- v) In the stroma, there are disc-like plates called grana connected by tubules called **stroma lamellae or intergrana or fret membranes**.
- vi) Each granum consists of 12 – 20 disc-like structures called **thylakoids**. These are arranged one above the other like a stack of coins.
- vii) Internal space of each thylakoid has ultra-microscopic particles called as **Quantasomes**.
- viii) In each quantasome, there are 230 - 300 molecules of photosynthetic pigments forming the pigment system.
- ix) DNA of chloroplast is circular, closed, naked ring and is called as **plastidome**.

Additional Information**Q.7. What is quantasome ?**

Ans: According to Park and Biggins, photosynthetic pigments are located in the membranes of thylakoids in specific areas called quantasome. Quantasome is a photosynthetic unit, believed to have about 160 molecules of chlorophyll-a, 70 molecules of chlorophyll-b and 50 carotenoid molecules.

Q.8. Write a note on Granum.

- Ans:**
- i) In stroma, small dark green, cylindrical granular sacs called grana are present. There may be 40-60 grana present in each chloroplast.
 - ii) A single granum is composed of stack of 12-20 sac-like thylakoids.
 - iii) Each thylakoid has large number of spherical bodies called quantasomes or photosynthetic units.
 - iv) Each quantasome has about 250 to 300 pigment molecules which are organized into two pigment systems, viz. PS-I and PS-II.
 - v) The granum, therefore, is well-equipped for the photochemical reaction of photosynthesis.

Q.9. Give the functions of grana and stroma.

Ans: Functions of grana :

- i) In grana, ATP and NADPH₂ are produced in presence of light.
- ii) Photolysis of water takes place to release O₂ in the atmosphere.
- iii) Cyclic and non-cyclic photophosphorylation takes place in grana.
- iv) It is the site for light reaction.

Functions of stroma :

- i) In stroma, CO₂ is fixed in absence of light to form hexose sugar.
- ii) ADP and NADP are produced which are necessary for the light reaction.
- iii) C₃ and C₄ cycles take place in the stroma.
- iv) It is the site of dark reaction.

Q.10. State the functions of chloroplast.

- Ans:**
- i) Chloroplast is called as the photosynthetic apparatus as both steps of photosynthesis are completed in it.
 - a) Light reaction takes place in the grana.
 - b) Dark reaction takes place in the stroma.
 - ii) All necessary enzymes needed for photosynthesis are found to be present in the chloroplast.

Q.11. Distinguish between Grana and Stroma.

Ans:

No.	Grana	Stroma
i)	The grana consists of quantasomes containing the pigment chlorophyll.	Proteinaceous matrix in the chloroplast is called matrix or stoma.
ii)	Light reaction occurs in grans	Dark reaction occurs in stroma
iii)	ATP, NADPH ₂ and O ₂ are produced in grana.	ATP and NADPH ₂ are used in stroma.
iv)	Photolysis of water and release of O ₂ occurs in grana.	Fixation of CO ₂ and synthesis of glucose occurs in stroma.

6.2 : Photosynthetic pigments and their role

Q.12. Name the various photosynthetic pigments.

Ans: Chlorophyll – a, Chlorophyll – b, Carotenoids (Carotenes, Xanthophylls), Phycobilins are the various photosynthetic pigments.

Q.13. What is the main function of chlorophyll pigment ?

Ans: The main function of chlorophyll pigment is to absorb light of specific wavelength in the visible region.

Q.14. State the location of pigments in the chloroplast.

Ans: In the chloroplast, photosynthetic pigments are located in the thylakoid membrane.

Q.15. What are photosynthetic pigments ?

- Ans:**
- A photosynthetic pigment is a pigment present in chloroplasts or photosynthetic bacteria and captures the light energy necessary for photosynthesis.
 - Photosynthesis is a photo-biochemical reaction which is mediated through the absorption of light energy.
 - The light energy is absorbed by photosynthetic pigments in plants.
 - These pigments have the capacity to absorb light of certain wavelength and reflect light of other wavelengths, imparting different colours to pigments.
 - The colour of specific pigment indicates the wavelength reflected by the pigment.
 - Different types of photosynthetic pigments are chlorophylls, carotenoids and phycobilins, etc.

Q.16. Describe different types of photosynthetic pigments and explain their role.

Ans: The three main types of photosynthetic pigments are Chlorophyll, Carotenoids (Carotenes, Xanthophylls) and Phycobilins.

Chlorophylls :

- Chlorophylls are the most important and abundant photosynthetic pigments.
- They are green pigments soluble in organic solvent and insoluble in water.
- They are of seven different types, viz. chlorophyll a, b, c, d, e, bacteriochlorophyll and bacterioviridin.
- Chlorophyll-a and chlorophyll- b are present in higher plants and green algae.

Chlorophyll – a :

- It is a blue green pigment with molecular formula $C_{55}H_{72}O_5N_4Mg$.
- It is present in all photosynthetic organisms (except photosynthetic bacteria).
- As chlorophyll-a converts light energy into chemical energy, it is the essential pigment or primary photosynthetic pigment.

Chlorophyll – b :

- It is a yellowish green pigment with molecular formula $C_{55}H_{70}O_6NMg$.
- It is found in higher plants, green algae, bryophytes and all vascular plants.
- Chlorophyll-b transfers the absorbed light to chlorophyll-a and functions as the accessory pigment.
- Both chlorophyll-a and chlorophyll-b show maximum absorption in blue, violet and red region of the visible spectrum.
- Chlorophyll c, d and e are found in algae along with chlorophyll-a.

Carotenoids :

- Carotenoids are fat soluble lipid compounds, widely distributed in chloroplasts and chromoplasts.
- They primarily absorb blue-violet region of visible light and transfer it to chlorophyll-a, thus function as accessory pigments.
- There are two types of carotenoids, viz. carotenes and xanthophylls.

Carotenes :

- Carotenes are orange/yellow in colour.
- They are unsaturated hydrocarbons with molecular formula $C_{40}H_{56}O_2$.
- They are insoluble in water and soluble in organic solvents like alcohol and benzene.
- β - carotene is the most common.

Xanthophylls :

- They are oxidized form of carotene with molecular formula $C_{40}H_{56}O_2$.
- They are yellow in colour.
- They are also insoluble in water and soluble in organic solvent.
- Lutein is the most widely distributed xanthophyll in plants, give yellow colour to autumn leaves.

Phycobilins :

- These are accessory pigments present in cyanobacteria and algae.
- They are water soluble pigments.
- Two examples of phycobilins are phycocyanins (blue) and phycoerythrins (red).

Q.17. Why is chlorophyll-a called essential pigment ?

Ans: Chlorophyll-a is called as an essential pigment because of the following reasons :

- Chlorophyll-a is the reaction center in the granum and is capable of converting solar energy into chemical energy.
- Chlorophyll-a absorbs solar energy as well as accepts energy from other accessory pigments.
- It plays an important role in both cyclic and non-cyclic photophosphorylation.
- It helps in photolysis of water and release of oxygen which is necessary for life.

Q.18. Which is the major Xanthophyll present in plants?

Ans: Lutein is the major Xanthophyll present in plants.

Q.19. Distinguish between Chlorophyll a and Chlorophyll - b.

Ans:

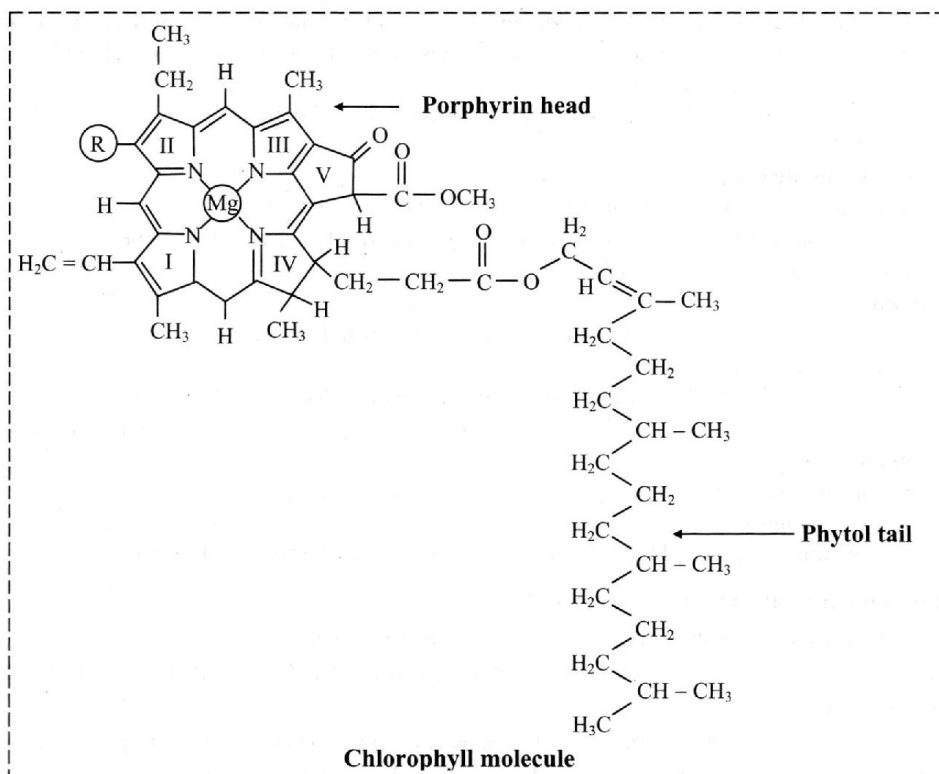
No.	Chlorophyll-a	Chlorophyll-b
i)	Empirical formula is $C_{55}H_{72}O_5N_4Mg$.	Empirical formula is $C_{55}H_{70}O_6N_4Mg$.
ii)	It is blue - green in colour	It is yellow - green in colour
iii)	It is primary photosynthetic pigment.	It is an accessory photosynthetic pigment.
iv)	It is soluble in petroleum	It is soluble in 90% methyl alcohol
v)	Carbon - 3 contains methyl group	Carbon - 3 contains aldehyde group

Q.20. Suppose there were plants that had high concentration of chlorophyll-b, but lacked chlorophyll-a. Would it carry out photosynthesis? Then, why do plants have chlorophyll-b and other accessory pigments?

Ans: Photosynthesis cannot be carried out without the presence of pigment chlorophyll a. P_{700} acts as a reaction centre of PS - I and P_{680} acts as a reaction centre of PS - II. Chlorophyll-b and other accessory pigments are able to absorb shorter wavelengths and then transfer their energy to chlorophyll-a for photophosphorylation. Such accessory pigments not only enable a wider range of wavelength of incoming light to be used for photosynthesis but also protect chlorophyll-a from photo-oxidation.

Q.21. Describe the structure of a typical chlorophyll molecule.

Ans:



- i) Both chlorophyll-a and chlorophyll-b are similar in their molecular structure, except that the methyl group (-CH₃) in chlorophyll-a is replaced with aldehyde group (-CHO) in chlorophyll-b.
- ii) A typical chlorophyll molecule has porphyrin head and phytol tail.
- iii) It looks like a kite.
- iv) Head is polar, rhomboid with four pyrrole rings, attached to each other by methine group.
- v) In the centre of these rings, there is non-ionic Mg atom.
- vi) The head is hydrophilic and is found in the protein part of thylakoid membrane.
- vii) A long non-polar phytol tail is attached to the 4th pyrrole ring.
- viii) It is lipophilic and extends in lipid layer of thylakoid membrane.

Q.22. Write a note on nature of light and its role in photosynthesis.

Ans: Nature of light :

- i) Light energy shows dual nature. It behaves as wave form during propagation, while on interaction with matter, it behaves as a stream of discrete packets of energy known as photons or light quanta.
- ii) A quantum is the amount of energy present in a photon. This energy is absorbed by the photosynthetic pigments.
- iii) Visible light useful in photosynthesis is only a small part of the spectrum ranging from 390 nm (violet light) to 760 nm (red light). This portion is often referred to as **photosynthetically active radiation (PAR)**.
- iv) The energy content of a photon is inversely proportional to the wavelength of light. Shorter the wavelength greater is the energy and vice-versa.

Role of light :

- i) Absorption of visible light by photosynthetic pigments is maximum in red and blue part, while it is little in yellow and orange part. Green part shows negligible absorption.
- ii) Accordingly, maximum photosynthesis occurs in red light followed by blue light, while green light shows little or no photosynthesis.

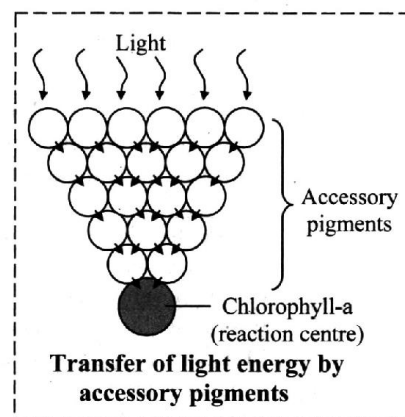
Q.23. Which wavelength of visible spectrum are absorbed maximum by chlorophyll and which wavelength of light are least absorbed ?

Ans: Blue and red wavelength of light are absorbed maximum by chlorophyll pigment and green wavelength is least absorbed.

Q.24. Explain the role of accessory pigments in photosynthesis.

Ans: Role of accessory pigments :

- i) Photosynthetic pigments such as chlorophyll-b, carotenes and xanthophylls are called accessory pigments.
- ii) These pigments absorb light energy of different wavelengths and transfer it to chlorophyll-a.
- iii) The light (radiation energy) captured by these pigments is funneled into the reaction centre for conversion into the chemical energy.
- iv) Carotenoids (carotenes and xanthophylls) protect chlorophyll-a from photo-oxidation.



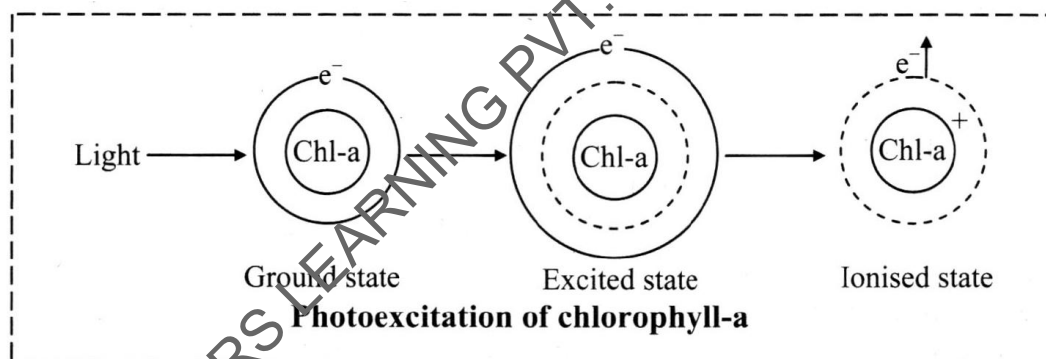
Q.25. Explain the photoexcitation of chlorophyll-a.

Ans: Photoexcitation of chlorophyll-a :

- i) Chlorophyll-a is the essential photosynthetic pigment as it converts light energy into chemical energy and acts as a reaction centre.
- ii) Initially, it lies at ground state or singlet state but when it absorbs or receives photons (solar energy), it gets activated and goes in excited state or excited second singlet state.
- iii) In the excited state, chlorophyll-a emits an electron. The emitted electron is energy rich, i.e. has extra amount of energy.
- iv) Due to the loss of electron (e^-), chlorophyll-a becomes positively charged. This is the ionized state.

Chlorophyll-a molecule cannot remain in the ionized state for more than 10^{-9} seconds.

- v) The energy rich electron is then transferred through various electron acceptors and donors (carriers).
- vi) During the transfer, the electron emits energy which is utilized for the synthesis of ATP. This shows that light energy is converted into chemical energy in the form of ATP.
- vii) There are the two forms of chlorophyll-a, P_{700} and P_{680} which form reaction centres of PS-I and PS-II respectively for the photochemical reaction.



Q.26. What do you mean by two pigment system ?

- Ans: i) The accessory pigments and the reaction centre together form pigment system or photosystem.
- ii) In higher plants, photosynthetic photochemical reactions are promoted by two pigment systems.
 - iii) These pigment systems are called pigment system I and pigment system II (or photosystem I (PS-I) and photosystem II (PS-II)).
 - iv) In PS-I, chlorophyll-a shows maximum absorption at 700 nm, thus P_{700} is the reaction centre.
 - v) In PS-II, chlorophyll-a shows maximum absorption at 680 nm, thus P_{680} is the reaction centre.
 - vi) During photosynthetic photochemical reactions, these two pigment systems work independently inside the photosynthetic apparatus, i.e. chloroplast.
 - vii) In PS-II, manganese, calcium and chloride ions are present in addition to the electron carrier. These ions play an important role in photolysis of water.
 - viii) Each photo system is with Core Complex (CC) and Light harvesting complex (LHC).

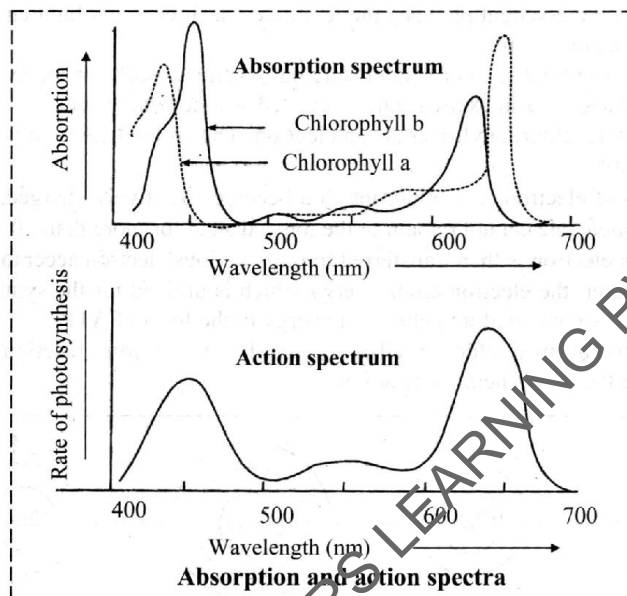
Q.27. Distinguish between PS-I and PS-II.

Ans:

No.	PS - I	PS - II
i)	It has P_{700} as the reaction centre.	It has P_{680} as the reaction centre.
ii)	PS-I is located on the outer surface of thylakoid	PS -II is located on the inner surface of thylakoid, i.e. in the stroma.
iii)	Chlorophyll-b is absent.	Chlorophyll - b is present.
iv)	It is involved in cyclic as well as non-cyclic	It is involved in only non-cyclic photophosphorlation
v)	It is not invloved in photosysis of water	It is involved in the photolysis of water
vi)	Molecular oxygen is not evolved in this system	It involves the evolution of molecular oxygen.
vii)	It donates the electrons to Ferredoxin Reducing	It donates the electrons to Quinone

Q.28. Explain absorption and action spectrum.

Ans:



i) Absorption spectrum :

- The graph showing the absorption of light by pigments at different wavelengths is called absorption spectrum.
- It is studied with the help of an instrument called spectrophotometer.
- Absorption spectrum of chlorophyll-a and chlorophyll-b shows that, they absorb in both blue and red region of the spectrum.

ii) Action spectrum :

- The graph showing the rate of photosynthesis at various wavelengths is called action spectrum.
- The rate of photosynthesis is measured in terms of O₂ evolved and CO₂ utilized.
- Action spectrum graph shows that rate of photosynthesis is more in red than in blue.

6.3 : Light Dependent Reactions

Q.29. What are light dependent reactions ?

Ans: The 'light-dependent reactions' is also called as photochemical phase or primary phase. The 'light-dependent reactions' or light reactions are the first stage of photosynthesis that occurs in grana of chloroplast, the process by which plants capture and store energy from sunlight. In this process, light energy is converted into chemical energy in the form of the energy-carrying molecule ATP.

Q.30. "Hill's experiment does not prove that the source of oxygen evolved during photosynthesis is water". This statement is true or false? Explain.

Ans: Robert Hill proved that source of oxygen evolved during photosynthesis is water and not carbon dioxide. Hence, it is called Hill's Reaction.

- In this experiment, Hill suspended isolated chloroplasts in a medium free of CO₂.
- Ferric salts and haemoglobin were added in the medium as hydrogen and oxygen acceptors respectively.
- When the suspension was exposed to light, he found that ferrous salts and oxyhaemoglobin were formed.
- This indicates that water molecule splits into H⁺ and OH⁻ ions, which are accepted by ferric salts and haemoglobin.
- This process of splitting up of water molecules under the influence of light in the presence of chlorophyll is called **Photolysis of water**.
- Hill's reaction can be represented as follows :

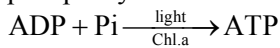
$$2\text{H}_2\text{O} + 2\text{A} \rightarrow 2\text{AH}_2 + \text{O}_2$$
 (Where A is a hydrogen acceptor)

Q.31. What was used to prove that source of oxygen evolved during photosynthesis is water?

Ans: Ferric salts (as hydrogen acceptor) and haemoglobin (as oxygen acceptor) were used to prove that source of oxygen evolved during photosynthesis is water.

Cyclic and non-cyclic photophosphorylation**Q.32. Define photophosphorylation.**

Ans: Formation of ATP molecules from ADP and inorganic phosphate (Pi) in presence of light and chlorophyll during the photochemical phase of photosynthesis is called photophosphorylation or photosynthetic phosphorylation. It can be represented as follows:

**Q.33. Describe non-cyclic photophosphorylation/ Z-Scheme.**

Ans: Non-cyclic photophosphorylation involves the following steps:

i) Photoexcitation of PS-II :

PS-II absorbs light and gets excited, which results in ionisation of chlorophyll-a and a high energy electron is expelled from PS-II.

ii) Electron Acceptors :

The expelled energy rich electron is first accepted by CO-Q (co-enzyme quinone). Electron from CO-Q moves down through various electron carriers and releases energy. From CO-Q, electrons are transferred to plastoquinone (PQ) (it is an iron containing protein). From PQ, electrons are transferred to cytochrome complex (cytochrome-b and cytochrome-f). From cytochrome complex, the electrons are transferred to plastocyanin (PC) (it is a copper containing protein). From PC, the electrons are finally accepted by ionized chlorophyll of PS-I.

iii. Synthesis of ATP :

One ATP is synthesized when electron passes from cytochrome b6 to cytochrome f.

iv) Photoexcitation of PS-I :

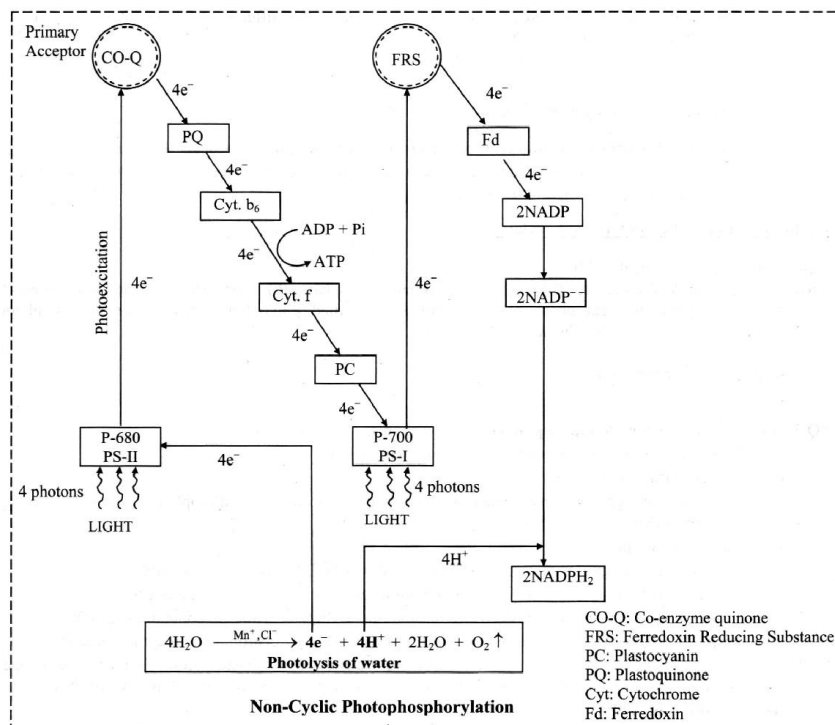
The light energy absorbed by PS-I is transferred to reaction centre P₇₀₀. It gets excited and expels energy rich electrons. The electrons are first accepted by unknown electron acceptor called FRS (Ferredoxin Reducing Substance). Electron from FRS moves down through various electron carriers and release energy. From FRS, electrons are transferred to ferredoxin (it is an iron containing protein). The reduced ferredoxin transfers electron to NADP to form NADP⁻ in the presence of enzyme Fd-NADP-reductase.

v) Photolysis of water :

Splitting of water into H⁺ and OH⁻ in presence of light and chlorophyll is called photolysis of water. Manganese, calcium and chloride ions present in PS-II play an important role in photolysis of water. Photolysis of water occurs in order to satisfy the electron need of PS-II and proton need of NADP⁻.

vi) Assimilatory power :

ATP and NADPH₂ are together called as assimilating power by Calvin, as it is required for assimilation of CO₂

**Q.34. Which substance acts as hydrogen acceptor in plants when photolysis of water takes place?**

Ans: In plants, NADP acts as hydrogen acceptor in plants when photolysis of water takes place.

Q.35. What is photolysis of water? Give the significance of photolysis of water.

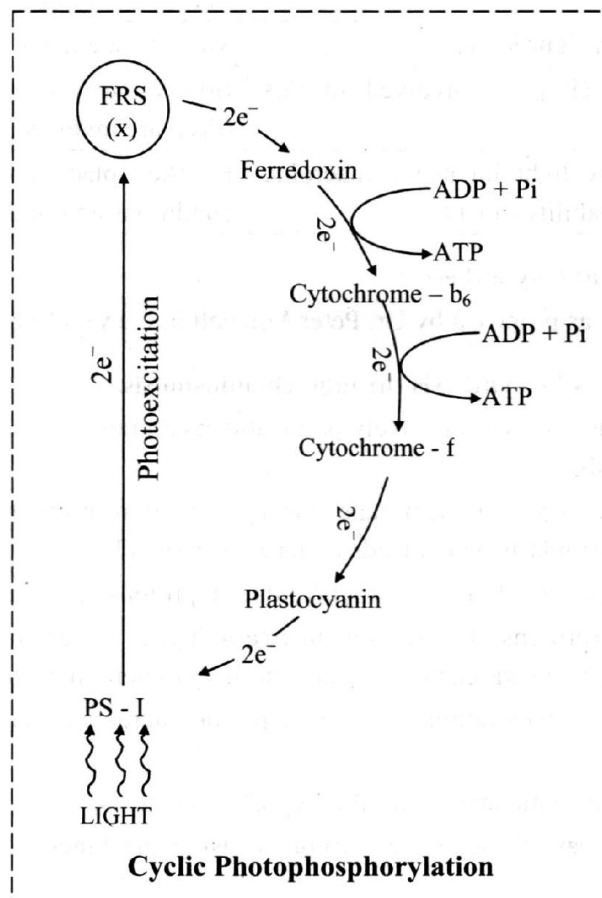
Ans: Photolysis of water: It is the process of splitting up of a water molecule into H^+ OH^- ions under the influence of light.

Significance of Photolysis :

- It results in the release of O_2 which is indispensable for life.
- it supplies H_2 for reduction of CO_2 .
- It supplies electron for neutralization of chl-'a' of PS II in non-cyclic photophosphorylation.

Q.36. Describe briefly cyclic photophosphorylation.

- Ans:**
- It involves the pigment system I, i.e. the reaction centre is made by P700 chlorophyll.
 - When light falls on the PS-I, it gets excited, the accessory pigments pass on the energy to the reaction centre P_{700} which emits a pair of energy rich electrons.
 - These electrons are accepted by the electron acceptor called Ferredoxin Reducing Substance (FRS).
 - From FRS, the pair of electrons are transferred through a series of electron carriers, i.e. Ferredoxin (Fd), Cytochrome b_6 , Cytochrome f and Plastocyanin (PC).
 - From Plastocyanin, the electrons return back to the P_{700}^+ chlorophyll molecule.
 - During the transfer of electrons between Cytochrome b_6 and Cytochrome f, the energy released is used to form ATP. However, ATP formation may also take place when electrons are transferred from ferredoxin to cytochrome $-b_6$.
 - The electrons released by the chlorophyll ultimately return back and hence it is called as Cyclic photophosphorylation.



Q.37. Under which condition cyclic photophosphorylation will take place ?

Ans: When photo system-I is illuminated by light, P_{700} (reaction centre) is excited and emits out energy rich electron which is first accepted by FRS and then transferred through a series of electron carriers. The electron released ultimately returns back to PSI. Thus, cyclic photophosphorylation takes place.

Q.38. What are cytochromes ?

Ans: Cytochromes are electron carrier proteins that catalyze intracellular oxidations.

Q.39. Give significance of cyclic and non cyclic photophosphorylation.

Ans: Significance of cyclic photophosphorylation :

- i) ATP molecules are produced which are required for synthesis of glucose.
- ii) ATP molecules are essential for the dark reaction.

Significance of non-cyclic photophosphorylation:

- i) ATP molecules as well as NADPH₂ are produced.
- ii) Photolysis of water takes place to release O₂.

Q.40. Differentiate between Cyclic and Non-cyclic photophosphorylation.

Ans:

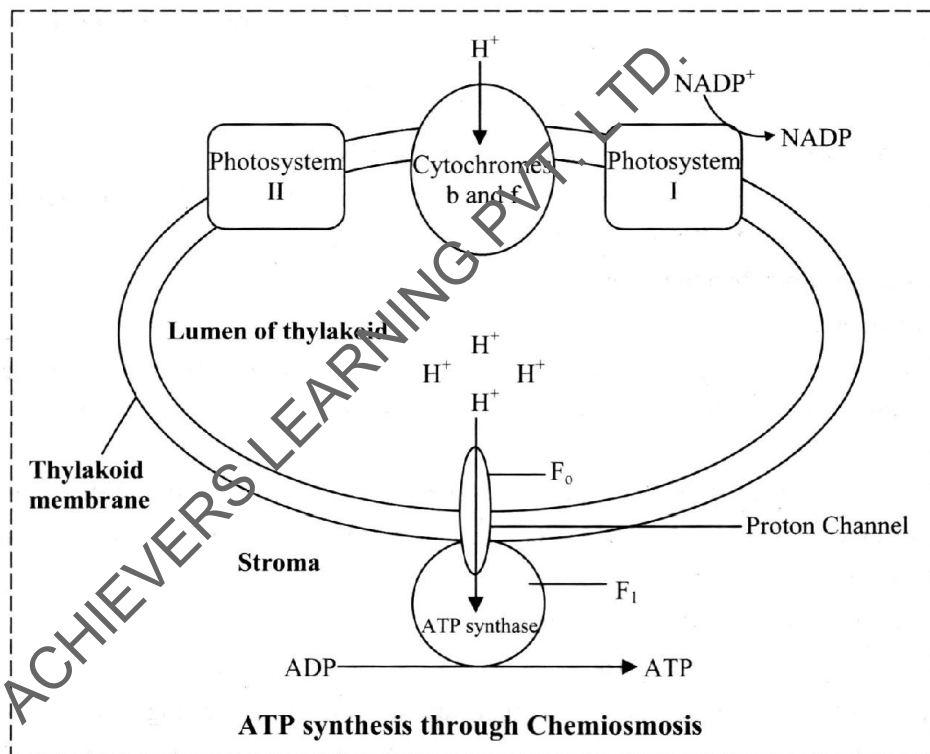
No.	Cyclic Photophosphorylation	Non - cyclic Photophosphorylation
i)	Electrons emitted by chlorophyll return back to the same chlorophyll.	The electrons emitted by chlorophyll do not return back to the same chlorophyll.
ii)	NADPH ₂ is not formed.	NADPH ₂ is formed.
iii)	Does not involve photolysis of H ₂ O	Involves photolysis of H ₂ O
iv)	No evolution of O ₂	There is evolution of O ₂
v)	Less efficient and less significant	More efficient and significant process.
vi)	Only Photosystem-I (P ₇₀₀) is involved in this cycle	Both Photosystem PS-I (P ₇₀₀) as well as PS-II (P ₆₈₀) are involved.
vii)	It operates under low light intensity, anaerobic conditions, poor availability of CO ₂	It takes place under optimum light, aerobic conditions and in the presence of sufficient CO ₂

Q.41 Explain the mechanism of ATP synthesis through chemiosmosis.

Ans: i) The movement of ions across a selectively permeable membrane, down their electrochemical gradient is called **chemiosmosis**.

- ii) Hydrogen ions move across a membrane during cellular respiration in mitochondria and during photosynthesis in chloroplasts, which leads to generation of ATP.
- iii) In photosynthesis, these membranes are thylakoids and protons accumulate in the lumen.
- iv) When hydrogen ions (protons) diffuse from an area of higher proton concentration to an area of lower proton concentration, an electrochemical concentration gradient of protons is developed.
- v) This electrochemical concentration gradient of protons across a membrane could be harnessed to make ATP.
- vi) **ATP synthase** is the enzyme that makes ATP by chemiosmosis.
- vii) It allows protons to pass through the membrane using the kinetic energy to phosphorylate ADP making ATP.
- viii) It allows protons to pass through the membrane using the kinetic energy to phosphorylate ADP making ATP.
- viii) Due to splitting of water molecule on the inner side of the membrane, hydrogen ions accumulate within the lumen of thylakoids.
- ix) The NADP reductase enzyme is located in the stroma side of the membrane.
- x) For reduction of NADP to NADPH₂, protons are required along with electrons that come from ferredoxin.
- xi) Hence, within the chloroplast, protons in the stroma decrease in number, while in the lumen, there is increase in the number of protons.
- xii) This creates a proton gradient across the thylakoid membrane.

- xiii) There is subsequent spontaneous movement of protons generating energy which is used for the synthesis of ATP.



6.4 : Light Independent Reaction

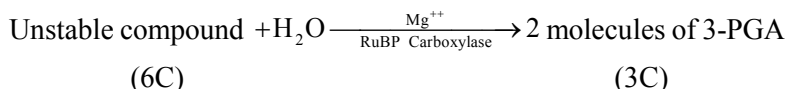
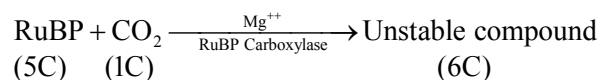
Q.43. Give an account of Calvin cycle.

Ans: Calvin cycle: The entire process of dark reaction was traced by Melvin Calvin, an American scientist along with his associates. Hence, the process is called as Calvin cycle. Since the first stable product formed is a 3-carbon compound, it is also called as C_3 pathway and the plants are called C_3 plants. It is also called biochemical phase because in this phase, chemical form of energy, i.e. ATP is converted into biological form, i.e. Glucose. It is also called synthesis phase or secondary phase. Presence of dark reaction was first established by Blackman, so it is called Blackman's reaction.

The cycle is divided into the following phases :

a. Carboxylation phase :

RuBP (Ribulose-1,5-bisphosphate) accepts atmospheric CO_2 in the presence of enzyme RuBP carboxylase (RuBisCO) and forms a 6-carbon unstable compound. This unstable compound soon splits into two molecules of 3-carbon compound called PGA (Phosphoglyceric acid) in presence of the same enzyme :



b. Reduction phase (utilization of assimilatory power) :

- The phosphoglyceric acid molecules are first phosphorylated by using ATP to produce 1,3 di-phosphoglyceric acid.
- It is then reduced by using $NADPH_2$ to produce phosphoglyceraldehyde (PGAL) and inorganic phosphate is released.
 $3\text{PGA} + \text{ATP} \longrightarrow 1,3\text{-diphosphoglyceric acid} + \text{ADP}$
 $1,3\text{-diphosphoglyceric acid} + \text{NADPH}_2 \longrightarrow 3\text{PGAL} + \text{NADP} + \text{Pi}$
- Some molecules of 3 PGAL are converted into its isomer dihydroxyacetone phosphate (DHAP) in presence of enzyme triose phosphate isomerase.

c) **Synthesis of sugar and Regeneration phase :**

Synthesis of sugar :

- For the synthesis of one molecule of glucose, six molecules of RuBP and six molecules of CO_2 are required, i.e. six turns of Calvin cycle are required. for the synthesis of one molecule of glucose.
- Out of 12 molecules of PGAL, 2 molecules (i.e. $1/6^{\text{th}}$ part) are used for the synthesis of glucose.
- A molecule of PGAL and DHAP combine together to form a molecule of fructose 1, 6- diphosphate as shown below :

$$3 \text{ PGAL} + \text{DHAP} \rightarrow \text{Fructose-1,6-diphosphate}$$

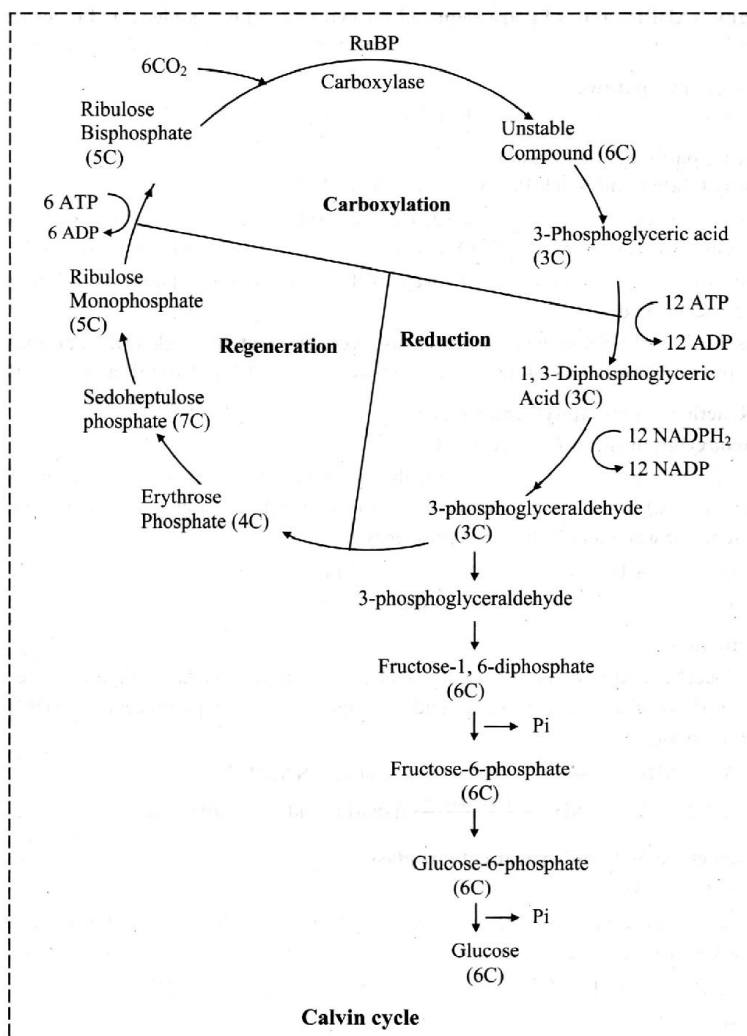
$$(3\text{C}) \quad (3\text{C}) \quad (6\text{C})$$
 [Note: Fructose-1,6-diphosphate is the first carbohydrate formed during this process]
- Fructose-1,6-diphosphate undergoes dephosphorylation to form fructose-6-phosphate which on isomerization forms glucose-6-phosphate.
- Glucose-6-phosphate undergoes dephosphorylation to form glucose. Glucose, thus formed is either utilized or stored as starch.

Regeneration phase :

- RuBP gets regenerated through many biochemical reactions called sugar phosphate interconversions.
- All the intermediate compounds formed like erythrose-4-phosphate, xylulose-5-phosphate, ribose-5-phosphate, sedoheptulose-7-phosphate, etc. are sugar phosphates.
- Out of 12 molecules of PGAL, 10 molecules are utilized for the regeneration of 6 molecules of RuMP (ribulose monophosphate) which on phosphorylation form RuBP as shown below :

$$12 \text{ PGAL} \rightarrow 6 \text{ RuMP} \quad \dots(\text{i})$$

$$6 \text{ RuMP} + 6 \text{ ATP} \rightarrow 6 \text{ RuBP} \quad \dots(\text{ii})$$
- Thus, RuBP which is necessary for the reduction of CO_2 is regenerated to keep the process going.



Significance of C₃ pathway :

- CO₂ is reduced to form organic food in the form of 3-phosphoglyceraldehyde (3C) or glucose (6C) by using ATP and NADPH₂. It can be utilized directly in plant metabolism or can be stored in the form of starch.
- ATP and NADPH₂ are utilized as energy and hydrogen donor to form ADP and NADP respectively for reuse in the photochemical (light) reaction.

Q.44. Which is the ultimate pathway for fixing carbon dioxide (CO₂) into glucose? [Mar 2014]

Ans: C₃ pathway (Calvin cycle) is the ultimate pathway for fixing carbon dioxide (CO₂) into glucose.

Q.45. Which is the first CO₂ acceptor in C₃ pathway? [Oct 2014]

Ans: The first CO₂ acceptor in C₃ pathway is Ribulose-1, 5 - diphosphate (RUDP).

Q.46. How many ADPH₂ and ATP are required for synthesis of one molecule of glucose?

Ans: 12 NADPH₂ and 18 ATP molecules are required for synthesis of one molecule of glucose.

Q.47. Who proposed C₄ pathway ?

Ans: The C₄ pathway was proposed by Hatch and Slack (1966).

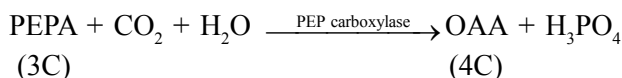
Q.48. Describe C₄ pathway with examples.

Ans: C₄ pathway (Hatch and Slack Pathway) or H.S.K. Pathway :

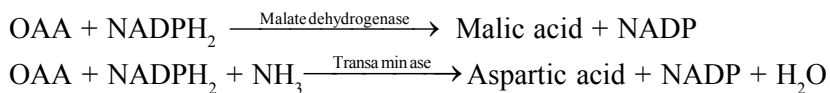
- Certain tropical plants like maize, sugarcane, jowar, *Amaranthus*, *Portulaca*, *Chenopodium*, *Atriplex*, etc. have low concentration of CO₂ due to which they follow alternative pathway.
- This pathway is known as C₄ pathway as the first stable compound is a 4-carbon compound, i.e. Oxaloacetic acid (OAA).
- It is also called HSK pathway as it was discovered by **Hatch, Slack and Kortschak**. The reactions occurring in this pathway are completed in two parts at two different sites as given below :

Part I (Reactions in mesophyll chloroplasts):**i) Carboxylation (First CO₂ fixation) :**

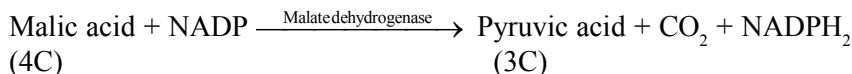
Initially, the atmospheric CO₂ entering the mesophyll chloroplasts is accepted by PEPA (Phosphoenol pyruvic acid), a 3-carbon compound to form a 4-carbon compound called Oxaloacetic acid in the presence of water and PEP carboxylase enzyme.

**ii) Reduction :**

Oxaloacetic acid is reduced to malic acid by the enzyme Malate dehydrogenase in the presence of NADPH₂ or changed to aspartic acid by amination in the presence of NADPH₂ and the enzyme transaminase.

**Part II (Reactions in bundle sheath chloroplasts)****i) Decarboxylation :**

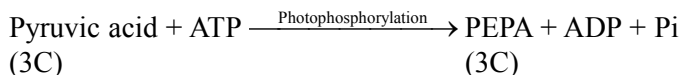
Malic acid or aspartic acid is then transported to the bundle sheath chloroplasts where it undergoes decarboxylation in the presence of NADP to form pyruvic acid with the release of CO₂.



Note : In case if aspartic acid is formed, it undergoes deamination to form pyruvic acid.

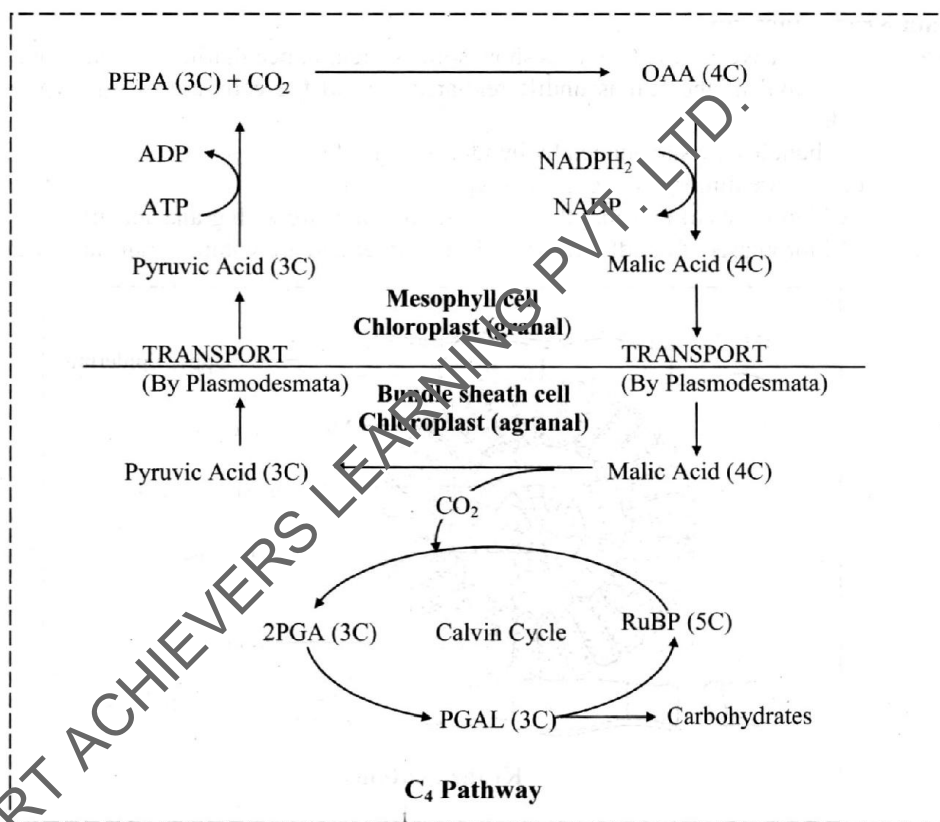
ii) Second CO₂ fixation :

The released CO₂ is accepted by RuBP (second carbon acceptor). It enters the Calvin cycle and eventually forms glucose which is stored as starch in bundle sheath chloroplasts. Pyruvic acid produced due to decarboxylation of malic acid is transported to mesophyll cells where it undergoes phosphorylation to regenerate PEPA as shown below :



- Thus, it is obvious that in C₄ plants, CO₂ is fixed twice in two different cells during the day time. CO₂ fixation in C₄ plants can occur at very low concentrations of CO₂, i.e. as low as photosynthesis even

if the light intensity is high, temperature is high and the amount of available water is less.



Q.49. Why light independent reactions cannot take place during day?

- Ans:**
- Light independent reactions do not require direct light.
 - ATP and NADPH₂ produced during the day time are used in light independent reactions. Hence, light independent reactions cannot take place during the day.

Q.50. RuBisCO is an enzyme that acts both as a carboxylase and oxygenase. Why do you think RuBisCO carries out more carboxylation in C₄ plants ?

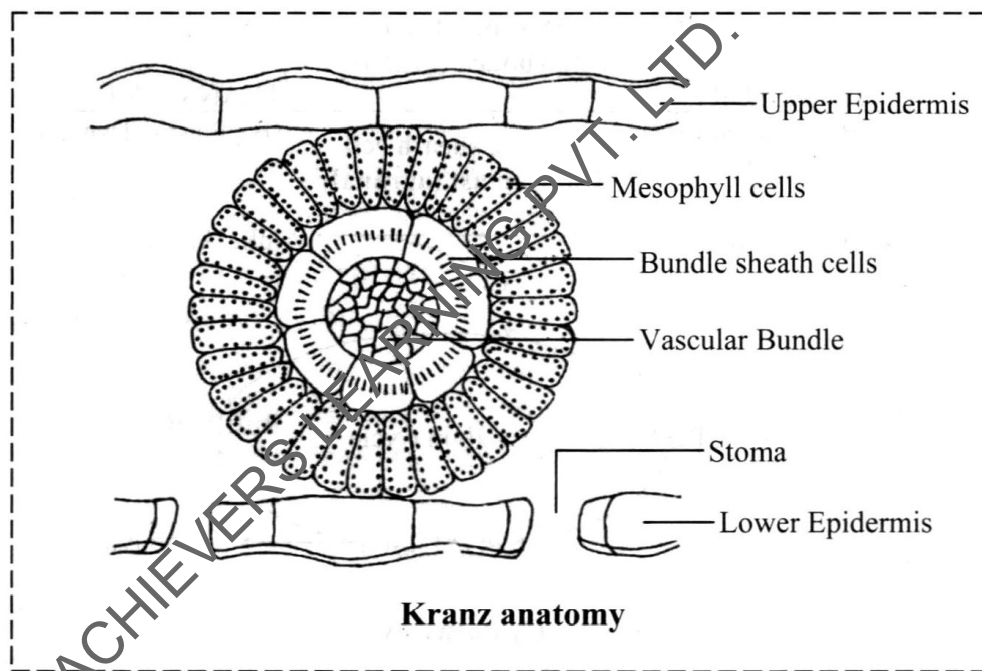
- Ans:**
- RuBisCO which is the most abundant enzyme in the world can bind to both CO₂ and O₂ on its active sites.
 - RuBisCO has much greater affinity for CO₂ than O₂. This binding is competitive.
 - It is the relative concentration of O₂ and CO₂ which determines which of the two will bind the enzyme.
 - The enzyme RuBisCO is absent in the mesophyll cells of C₄ plants. It is present in the bundle-sheath cells surrounding the vascular bundles.
 - In C₄ plants, the Calvin cycle occurs in the bundle-sheath cells, and light reaction occurs in mesophyll cells. Such arrangement does not allow O₂ released in mesophyll cells to enter in bundle sheath cells.
 - The primary CO₂ acceptor in the mesophyll cells is phosphoenol pyruvate - a three-carbon compound. It is converted into the four-carbon compound oxaloacetic acid (OAA).
 - In C₄ plants, a CO₂ concentrating mechanism is present which helps in reducing the occurrence of photorespiration.
 - OAA is further converted into malic acid. Malic acid is transported to the bundle-sheath cells, where it undergoes decarboxylation and CO₂ fixation occurs by the Calvin cycle. This prevents the enzyme RuBisCO from acting as an oxygenase.

Q.51. Explain Kranz anatomy.

Ans: Kranz anatomy : Leaves of the C₄ plants show some structural peculiarities called Kranz anatomy.

- The mesophyll of the leaf is undifferentiated, i.e. all the cells are of one type and are compactly arranged.
- Vascular bundles are surrounded by bundle sheath cells.

- iii) Chloroplasts are dimorphic, i.e. of two types :
- Chloroplasts of mesophyll cells are smaller and are with grana and arranged centrifugally.
 - Chloroplasts of bundle sheath cells are larger and are without grana and arranged centripetally.



Q.52. What is 'photorespiration'? Explain it with diagrammatic representation.

[Mar 2014]

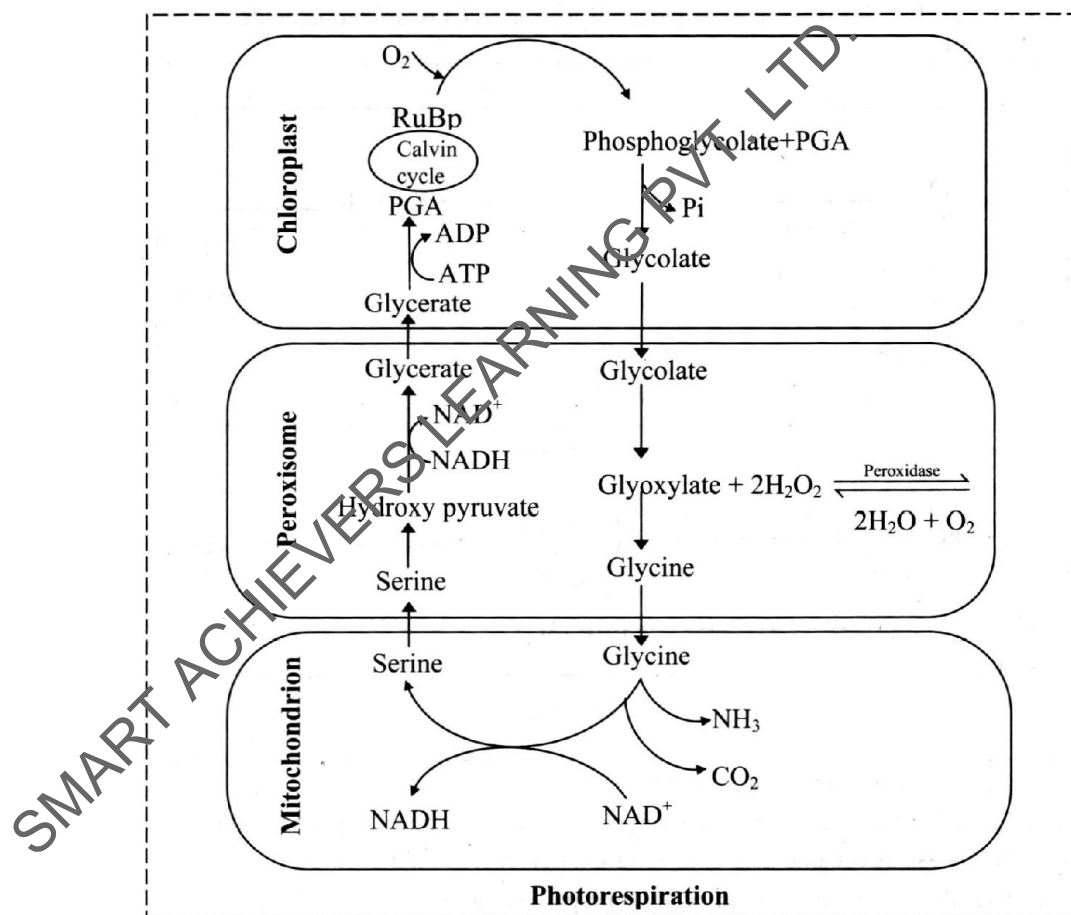
Ans: Photo respiration :

The process of respiration (oxidation) that is initiated in the chloroplast and takes place in the presence of light is called photorespiration.

Mechanism:

- Ribulose biphosphate carboxylase (main enzyme of Calvin cycle) has an ability to combine both CO_2 (carboxylation) and O_2 (oxygenation) with ribulose biphosphate (RuBP). Hence, the enzyme is called ribulose biphosphate carboxylase oxygenase (RuBisCO). In intense light, at low concentration of CO_2 (less than 1%) and increased concentration of O_2 , the enzyme brings about oxygenation of RuBP to phosphoglycolate (2C) and PGA (3C)
- Phosphoglycolate loses phosphate group to form glycolate and PGA is used in Calvin cycle.
- Glycolate synthesized in chloroplast is an early product which moves to peroxisomes. Glycolate is oxidized to glyoxylate and hydrogen peroxide with the help of enzyme oxidase.
- Glyoxylate is converted into amino acid glycine by transamination reaction in presence of enzyme transaminase.
- Glycine is then transported to mitochondria where two molecules of glycine interact to form one molecule of NH_3 , one molecule of CO_2 and one molecule of serine.
- Serine is taken up by peroxisome and through a series of reactions, it gets converted into glycerate which enters the chloroplast and gets phosphorylated to form PGA. PGA enters Calvin cycle to make carbohydrates. In this process, one ATP molecule gets converted into ADP. Thus, 75% of the carbon lost by oxygenation of RuBP is recovered, but 25% is lost as release of one molecule of CO_2 .
- Photorespiration is also called photosynthetic carbon oxidation cycle. It protects the plants from photo-oxidative damage.
- Photorespiration works to undo the act of photosynthesis as no energy rich compound (neither ATP nor NADPH_2) is produced in this process. Thus, it is a wasteful process. In high temperature and oxygen concentration, affinity of RuBP carboxylase for CO_2 decreases and for O_2 increases. Thus, photo respiration interferes with the process of photosynthesis. (In C_4 plants,

photorespiration does not occur because they have the mechanism that increases the concentration of CO_2 at enzyme site).



Q.53.Explain how photo respiration is avoided in C_4 plants ?

Ans:Photorespiration occurs in intense light and low concentration of CO_2 (less than 1%). However, in C_4 plants, light reaction and evolution of O_2 takes place in mesophyll cells and absorption of CO_2 by RuBP takes place in bundle sheath cells. In the bundle sheath cells, CO_2 concentration is more. Thus, possibility of oxygenation of RuBP is avoided and photorespiration does not take place.

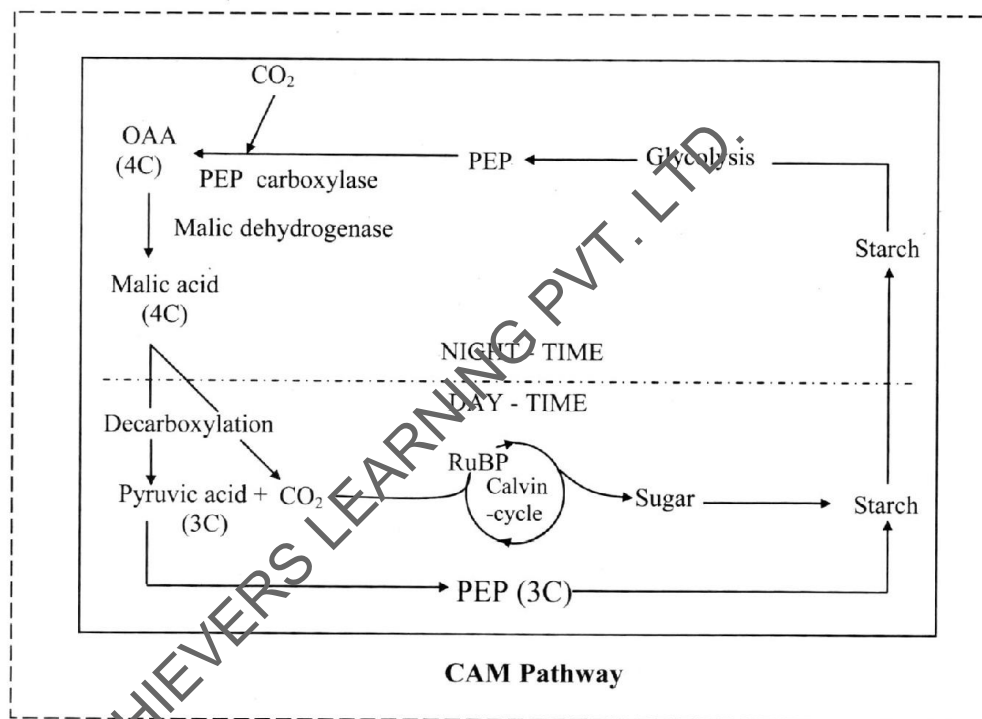
Q.54.Explain Crassulacean Acid Metabolism (CAM).

Ans:Crassulacean Acid Metabolism (CAM) is a specialized photosynthetic process which is characterized by the following criteria :

- CO_2 uptake takes place mainly at night.
- Stomata are open during the night and are closed during the day, when CO_2 uptake is almost negligible.
- Malate accumulates at night by carboxylation of PEP.
- Decarboxylation of malate during day yields CO_2 which is fixed by RuBP carboxylase. CAM has been named after the Family Crassulaceae in which the phenomenon was first observed. The examples exhibiting CAM are cacti, *Opuntia*, *Bryophyllum*, *Kalanchoe*, Pineapple, etc. In such plants, which grow in dry condition, stomata remains closed during day to check the loss of water due to transpiration. Thus, they show different mechanism for photosynthesis. The process of CAM is as follows :

During night time (when stomata are open):

- CO_2 is absorbed and fixed by Phosphoenol.pyruvic acid (PEP,3C) in presence of enzyme PEP carboxylase. As a result of this, PEP gets converted into Oxaloacetic acid (OAA,4C).
- OAA (4C) further gets transformed into malic acid (4C) in presence of enzyme malic dehydrogenase. This process is called acidification as CO_2 is fixed in acids.



During day time (when stomata are closed) :

- i) The malic acid gets converted into pyruvic acid (3C) liberating CO_2 . This process is called deacidification as organic acid concentration decreases to almost zero.
- ii) This CO_2 then enters the Calvin cycle to prepare carbohydrates.
- iii) Pyruvic acid gets converted into carbohydrates by reverse glycolysis. Thus, during night time, organic acid concentration of succulents increases and during day time, it decreases to almost zero. This day and night fluctuation in acid concentration is an essential feature of CAM plant.

Q.55. In CAM plants, why acid concentration increases during night ?

Ans: In CAM plants, malic acid accumulates during night, which is formed from Oxaloacetic acid in presence of the enzyme malate dehydrogenase.

Q.56. Even though a very few cells in C_4 plants carry out the biosynthetic - Calvin pathway, yet they are highly productive. Why ?

Ans: Although a very few cells in a C_4 plant carry out the biosynthetic-Calvin pathway, yet they are highly productive. This is due to the following reasons :

- i) C_4 plants have a high value of net assimilation at high temperatures.
- ii) Their rate of carbon assimilation is quite rapid.
- iii) C_4 plants perform photosynthesis even when stomata are closed as PEP has high affinity for CO_2 .
- iv) Their rate of net photosynthesis at full sunlight is as high as $40 - 80 \text{ mg CO}_2/\text{dm}^2/\text{hr}$.

Q.57. Give the significance of C_3 pathway and C_4 pathway.

Ans: Significance of C_3 pathway:

- i) Helps in the formation of carbohydrate by reduction of CO_2
- ii) It utilizes ATP and NADPH_2 to form ADP and NADP, which are used in light reaction.

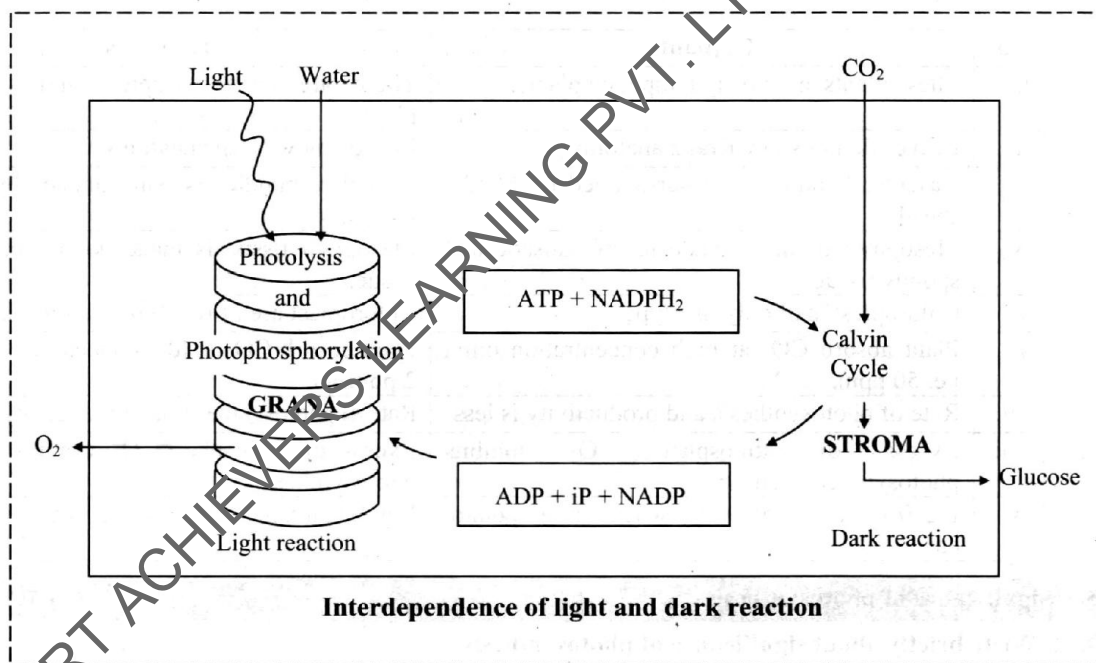
Significance of C_4 pathway :

- i) C_4 plants can grow well in the regions having water scarcity.
- ii) C_4 plants can photosynthesize at high temperature and high intensity of light.
- iii) PEP carboxylase is more efficient and can absorb CO_2 (though the concentration of CO_2 is less).
- iv) Productivity of C_4 plants is more than C_3 plants.

Q.58. Write a note on interdependence of light and dark reactions of photosynthesis.

- Ans:**
- i) The two reactions of photosynthesis, i.e. light and dark reactions are dependent on each other, because neither of them can continue the process of photosynthesis alone.
 - ii) For example, light reaction of photosynthesis generates ATP and NADPH_2 which are necessary for the fixation of carbon dioxide and formation of carbohydrate from it.

- iii) During dark reaction, ATP and NADPH₂ are transformed into ADP and NADP which are transferred to grana in which light reaction takes place.
- iv) ADP and NADP get recharged to form ATP and NADPH₂ to continue the fixation of CO₂ and formation of carbohydrate from it in dark reaction.
- v) Hence, light and dark reactions of photosynthesis are interdependent.



Q.59 Distinguish between Light and Dark Reaction.

Ans:

No.	Light Reaction	Dark Reaction
i)	It is a photochemical process.	It is a biochemical process.
ii)	It takes place in the presence of light	It is independent of light.
iii)	It takes place in the grana of chloroplast	It takes place in the stroma of chloroplast
iv)	Synthesis of ATP and NADPH ₂ takes place	Utilization of ATP and NADPH ₂ takes place.
v)	It involves photolysis of H ₂ O.	It involves fixation of CO ₂
vi)	Oxygen is released.	Carbohydrate is produced.

Q.60. Distinguish between C₃ and C₄ pathway.

[Sep 2008]

Ans:

No.	C ₃ Pathway	C ₄ Pathway
i)	C ₃ Pathway operates in algae, bryophytes and most of the vascular plants. e.g. wheat, oat, mango, China rose, etc.	C ₄ Pathway operates in few higher vascular flowering plants. e.g. maize, sugarcane, <i>Sorghum</i> , <i>Amaranthus</i> , <i>Portulaca</i> , etc.
ii)	The primary acceptor of CO ₂ is RuBP which is a 5-carbon compound.	The primary CO ₂ acceptor is phosphoenol pyruvic acid (PEPA), which is a 3-carbon compound.
iii)	The first stable compound is three carbon compound called Phosphoglyceric acid (PGA)	The first stable compound is Oxaloacetic acid (OAA), a four carbon compound.
iv)	Plants show normal leaf anatomy	Plants show Kranz anatomy of leaf
v)	CO ₂ is accepted when CO ₂ concentration is more than 50 ppm	CO ₂ is accepted even if CO ₂ concentration is as low as 1-2 ppm.
vi)	The rate of photosynthesis is affected, when photorespiration occurs.	Photorespiration is avoided.
vii)	Optimum temperature for the process is 10° to 30° C.	Optimum temperature for the process is 30° to 45° C.

Q.61. Distinguish between C_3 and C_4 plants.

Ans:

No.	C_3 Pathway	C_4 Pathway
i)	These plants are mostly temperate plants.	These are mostly tropical and subtropical plants.
ii)	Leaves do not show Kranz anatomy.	Leaves show Kranz anatomy.
iii)	Vascular bundle is not surrounded by bundle sheath.	Vascular bundle is surrounded by bundle sheath.
iv)	Mesophyll tissue is made up of palisade and spongy tissue.	Mesophyll tissue is made up of only spongy tissue.
v)	Chloroplast is of only one type.	Chloroplasts are of two types (dimorphic).
vi)	Plants absorb CO_2 at high concentration only, i.e. 50 ppm.	Plants absorb CO_2 at low concentration, i.e. 1–2 ppm.
vii)	Rate of photosynthesis and productivity is less.	Rate of photosynthesis and productivity is high.
viii)	Excess of atmospheric O_2 inhibits	Excess of atmospheric O_2 has no effect on photosynthesis.
ix)	E.g. Hibiscus, sunflower, wheat, rice, potato, etc.	E.g. Sugarcane, maize, jowar, Amaranthus, etc.

6.5 : Significance of photosynthesis**Q.62. Write briefly about significance of photosynthesis.**

Ans: Significance of photosynthesis :

- Photosynthesis is the most important natural process during which light energy is trapped and converted into chemical form of energy.
- Photosynthesis involves synthesis of food. Plants use this food as a source of energy and this food is made available for all heterotrophic organisms. All living organisms, directly or indirectly depend on this process for energy. (except chemoautotrophs.)
- Photosynthesis releases O_2 , which is indispensable for life, maintains balance of O_2 and CO_2 in the atmosphere and helps to purify air. (Oxygen in the atmosphere may be used for ozone formation.)
- Various fossil fuels like coal, petroleum and natural gas are products of photosynthesis occurred in the geological past.
- The plant products, such as cotton, alkaloids, resins, gums, tannins, steroids, rubber, timber, etc. are the products of photosynthesis, and are economically important.

Q.63. "Photosynthesis protects us from the harmful effects of ultraviolet radiations of the sun".

Comment on the statement.

- Ans: i) Oxygen released during photosynthesis gives rise to the layer of ozone which forms the uppermost layer of atmosphere, i.e. troposphere.
- ii) Ozone prevents the ultraviolet rays of sun from entering the atmosphere of the earth to protect the living beings from its ill-effects like skin cancer.

6.6 : Factors affecting rate of photosynthesis**Q.64. Explain the factors affecting rate of photosynthesis.**

Ans: The rate of photosynthesis is controlled by a number of factors such as:

External factors :

- Light :** Light is essential for photosynthesis as it provides energy for photosynthesis. The quality, intensity and duration of light influence the rate of photosynthesis significantly.
 - Quality :** Light between the wavelength 400 nm and 700 nm is most effective for photosynthesis. Maximum photosynthesis takes place in red light and minimum in green light.
 - Intensity :** The rate of photosynthesis steadily increases with the light intensity. However, if light intensity increases beyond a certain point, the chlorophyll undergoes photo-oxidation and is destroyed.
 - Duration :** Longer duration of light favours photosynthesis. Generally if the plants get 10 to 12 hours of light per day, it favours good photosynthesis.

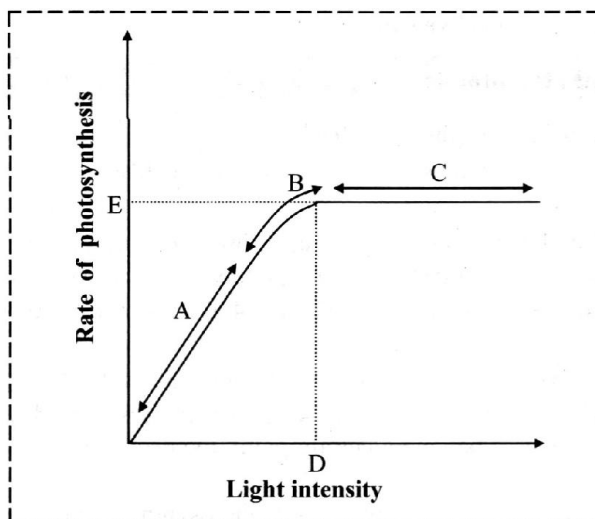
- ii) **CO₂**: The low concentration of CO₂ (0.03%) in the atmosphere acts as a limiting factor in natural photosynthesis, when other environmental factors (light temperature, water, etc) are optimum. If the CO₂ supply is increased up to a certain limit, the rate of photosynthesis increases. However, very high concentration of CO₂ becomes toxic to the plants.
- iii) **Water** : Water deficiency may decrease the rate as it is one of the raw materials for the process. Less availability of water may further check the rate by closing the stomata, thereby affecting the entry of CO₂.
- iv) **Temperature** : The optimum range of temperature for photosynthesis is from 10°C to 35°C. The rate of photosynthesis increases by increase in temperature upto 40°C. If temperature is increased too high, the rate of photosynthesis is also reduced due to denaturation of enzymes involved in the process.
- v) **Oxygen** : Excess of oxygen may have inhibitory effect on photosynthesis. Enhanced supply of O₂ increases the rate of respiration and simultaneously decreasing the rate of photosynthesis by utilizing the common intermediate substances. Besides, O₂ destroys the excited state of chlorophyll and thus inhibits photosynthesis.

Q.65. Explain Blackmann's law of limiting factors.

- Ans:** i) In 1905, Blackmann proposed the law of limiting factors according to which, "when a process is conditioned to its rapidity by a number of factors, the rate of process is limited by the pace of the slowest factor."
- ii) He studied the effect of CO₂ concentration, light intensity and temperature on the rate of photosynthesis.
 - iii) According to him, for every factor, there is a minimum value when no photosynthesis occurs, an optimum value showing highest rate and maximum value above which photosynthesis fails to take place.
 - iv) For example, if optimum light and CO₂ is available and temperature is very low, then rate of photosynthesis will be controlled by temperature, i.e. it will increase with increase in temperature and then, there will be a steady state.
Further increase in rate is possible only if there is increase in CO₂ concentration. Again, there will be steady state and further increase is possible if intensity of light increases.
 - vi) Thus, at a time only one factor controls the rate of photosynthesis and is called as limiting factor.

Q.66. Figure given below shows the effect of light on the rate of photosynthesis. Based on the graph, answer the following questions :

- i. At which point/s (A, B or C) in the curve light is a limiting factor ?
- ii. What could be the limiting factor/s in region A ?
- iii. What do C and D represent on the curve ?

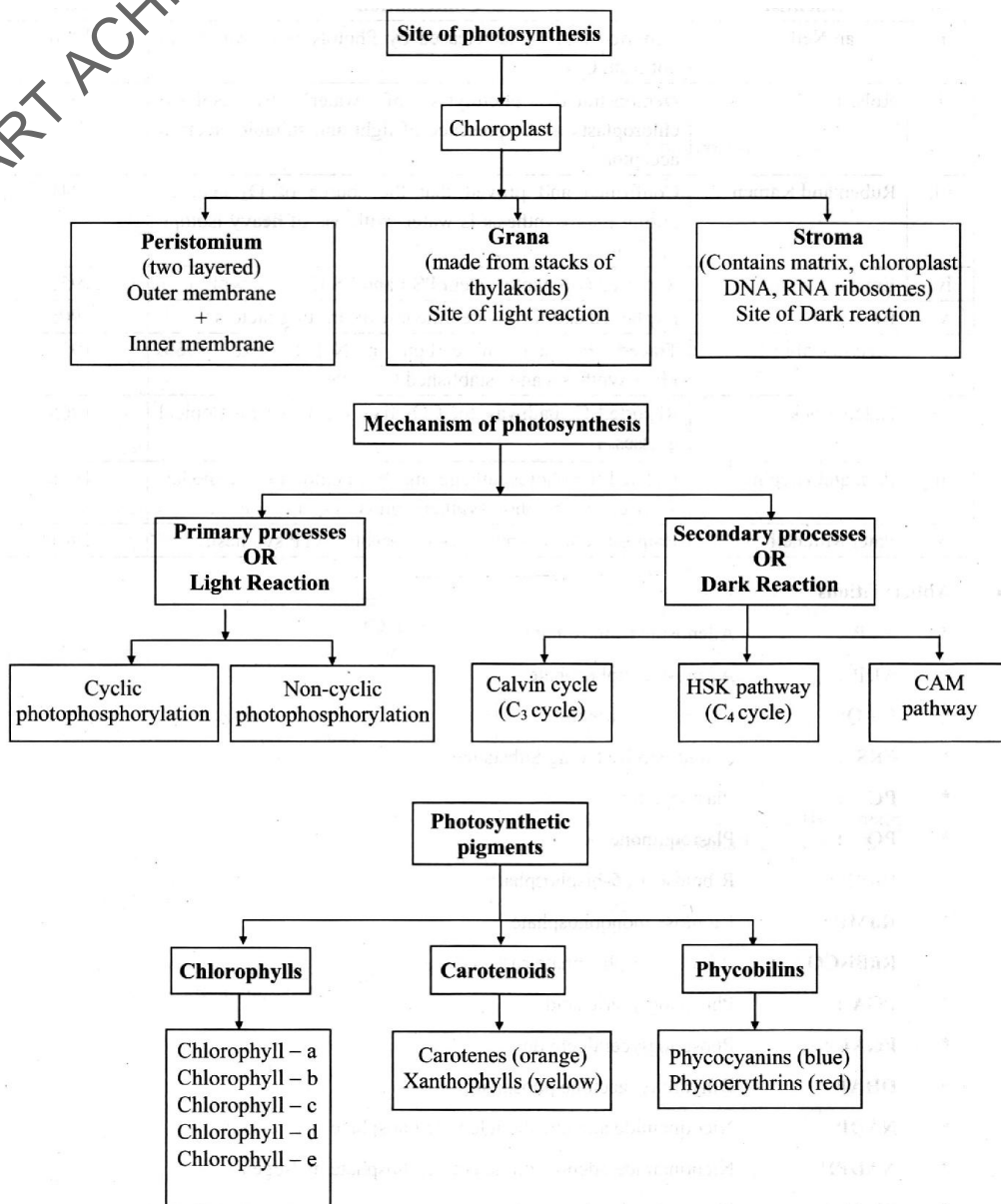


- Ans:** i) At point B
- ii) Carbon dioxide concentration and quantity of water may be the limiting factor in region A.
 - iii) C represents that rate of photosynthesis fails to increase, even by increasing light intensity because some other factor like CO₂ has become limiting. D is the light saturation point where the maximum amount of photosynthesis is achieved.

Additional Theory Questions

- Q.1. Explain how photosynthesis is a mode of autotrophic nutrition? Refer Q.2.
 Q.2. Draw a well labelled diagram of ultrastructure of chloroplast. Refer Q.6.
 Q.3. Describe Hill's reaction. [Sept 2009] Refer Q.30.
 Q.4. Write a short note on Hill's reaction. Refer Q.30.
 Q.5. Give diagrammatic representation of non-cyclic photophosphorylation. Refer Q.33.
 Q.6. Explain the process of cyclic photophosphorylation. [Mar 2013 Old Course] Refer Q.36.
 Q.7. Explain briefly Calvin cycle. [Sept 2009] Refer Q.43.
 Q.8. Describe C₃ pathway and give its significance. [Mar 2008] Refer Q.43.
 Q.9. Give schematic representation of Calvin Cycle. Refer Q.43.
 Q.10. Describe H.S.K. pathway of photosynthesis. [Mar 2010] Refer Q.48.
 Q.11. Give schematic representation of HSK pathway. Refer Q.48.
 Q.12. Describe dicarboxylic acid cycle. Refer Q.48.
 Q.13. Draw a labelled diagram of T.S. of a leaf showing Kranz anatomy. [Oct 2014] Refer Q.51.
 Q.14. What is photorespiration? Give its diagrammatic representation. [Oct 2013] Refer Q.52.
 Q.15. Explain how photosynthesis takes place during day in spite of stomata being closed, in certain plants. Refer Q.54.
 Q.16. Describe the ultrastructure of chloroplast. Add a note on the significance of photosynthesis. [Mar 2013] Refer Q.6 and 62.

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- **Scientists and their contribution**

No.	Scientists	Contribution	Year
i)	C. Van Neil	Reported that O ₂ is released by Photolysis of water and	1930
ii)	Robert Hill	not from CO ₂ Demonstrated 'Photolysis of water' by isolated chloroplasts in the presence of light and suitable electron acceptor.	1937
iii)	Ruben and Kamen	Confirmed and proved that the source of O ₂ evolved during photosynthesis is water, with use of heavy isotope of oxygen.	1941
iv)	Emerson et.al.	Reported two photosystem PS I and PS II.	1957
v)	Blackman	Explained and formulated the law of limiting factor	1905
vi)	Melvin Calvin	Traced the path of carbon in Nobel Prize, 1960 Photosynthesis and established C ₃ cycle.	1954
vii)	Hatch Slack	Reported C ₄ pathway for CO ₂ fixation in certain tropical grasses	1965
viii)	Park and Biggins	Isolated the photosynthetic unit from chloroplast lamellar	1946
ix)	Pater Mitchell	Proposed chemiosmotic hypothesis for ATP synthesis.	1961

- **Abbreviations**

- * **ATP** : Adenosine triphosphate
- * **ADP** : Adenosine diphosphate
- * **Co-Q** : Co-enzyme quinone
- * **FRS** : Ferredoxin Reducing Substance
- * **PC** : Plastocyanin
- * **PQ** : Plastoquinone
- * **RuBP** : Ribulose-1 , 5-bisphosphate
- * **RuMP** : Ribulose monophosphate
- * **RuBisCO** : Ribulose bisphosphate carboxylase
- * **PGA** : Phosphoglyceric acid
- * **PGAL** : Phosphoglyceraldehyde
- * **DHAP** : Dihydroxy acetone phosphate
- * **NADP** : Nicotinamide adenine dinucleotide phosphate
- * **NADPH₂** : Nicotinamide adenine dinucleotide phosphate hydrogen
- * **PEPA** : Phosphoenol pyruvic acid
- * **OAA** : Oxaloacetic acid

Multiple Choice Question

- Photosynthesis is reaction.
 - oxidation
 - reduction
 - redox
 - electrochemical
- Oxygen liberated during photosynthesis comes from
 - CO₂
 - glucose
 - H₂O
 - chlorophyll
- Which of the following is not required for Hill's reaction ?
 - Sunlight
 - Chlorophyll
 - Water
 - Carbon dioxide
- C₄ cycle was discovered by
 - Hill
 - Calvin
 - Hatch and Slack
 - Blackmann
- Which of the following shows chloroplast dimorphism ?
 - Sugar beet
 - Sugar cane
 - Potato
 - Papaya
- Which one of the following is C₄ plant ?

[Oct 2014J

 - Sunflower
 - Soyabean
 - Sugarcane
 - Spinach
- PS – I gets de-energized electrons from
 - water
 - plastoquinone
 - plastocyanin
 - cytochrome-f
- Which of the following was used in the study of dark reactions of photosynthesis ?
 - Hydrilla*
 - Chlorella and Scenedesmus*
 - Chlamydomonas*
 - Chlorella and Spirogyra*
- During light reaction of photosynthesis, how many photons are required for evolution of one O₂?
 - Six
 - Eight
 - Four
 - Two
- One-sixth part of the total PGAL produced, is used for the synthesis of
 - glucose
 - RUBP
 - RUMP
 - DHAP
- CAM plants are mostly
 - Tropical plants
 - Succulents
 - Monocots
 - Mangroves
- The internal source of CO₂ in CAM plants is
 - oxaloacetic acid
 - malic acid
 - RUBP
 - phosphoenol pyruvic acid
- Which pigment is absent in chloroplast ?
 - Xanthophyll
 - Anthocyanin
 - Chlorophyll-b
 - Carotene
- ATP is a source of energy for ____
 - light reaction in C₄ plants.
 - photophosphorylation.
 - biochemical reaction.
 - photolysis of water.
- In C₄ pathway, in which of the following cells is metabolic CO₂ fixed ?
 - Bundle sheath cells
 - Mesophyll cells
 - Epidermal cells
 - Cortical cells
- During photosynthesis, the process which occurs first is
 - photolysis of water.
 - ionization of chlorophyll.
 - synthesis of ATP
 - synthesis of NADPH₂
- Grana are connected by
 - inter-granal membranes
 - stroma lamellae
 - both a) and b)
 - thylakoids
- Granum is made up of
 - stroma
 - matrix
 - grana lamallae
 - thylakoids
- Quantasomes contain ____ molecules 'of pigments.
 - 150-200
 - 200-250
 - 250-280
 - 280-320
- The molecular formula for chlorophyll-a is
 - C₅₅H₇₂O₅N₄Mg
 - C₅₅H₇₀O₆N₄Mg
 - C₄₀H₅₆
 - C₄₀H₅₆O₂
- Photosynthesis is minimum in ____ light.
 - green
 - blue
 - red
 - yellow
- From the visible spectrum of light, which component is reflected by the green leaves ?

[Mar 2014J

 - Blue
 - Red
 - Green
 - Orange
- Chlorophyll a and b absorb and ____ light respectively.
 - blue and green
 - red and green
 - blue and red
 - red and violet
- Which of the following lights are absorbed by carotene and xanthophylls ?
 - Green
 - Blue
 - Yellow
 - Violet
- Which of the following is not an accessory pigment ?
 - Chlorophyll-b
 - Xanthophyll
 - Chlorophyll-a
 - Carotene
- The energy of each photon is called
 - quantasome
 - radiant
 - quantum
 - wavelength
- Which of the following was used in Hill's reaction ?
 - Chloroplast
 - Fe salts
 - Haemoglobin
 - Both b) and c)
- Light reactions occur in
 - stroma
 - grana
 - matrix
 - fret
- In cyclic photophosphorylation, the first electron acceptor is
 - FRS
 - CO-Q
 - Plastocyanin
 - Cytochrome f

30. In non-cyclic photophosphorylation, the first electron acceptor is
 a) FRS b) CO-Q
 c) Plastocyanin d) Cytochrome f
31. In cyclic photophosphorylation, ATP IS synthesized during
 a) ferredoxin – cytochrome b_6
 b) cytochrome b_6 – cytochrome f
 c) cytochrome f – plastocyanin
 d) cytochrome b_6 - plastocyanin
32. In non-cyclic photophosphorylation, the electrons released by Ferredoxin are accepted by
 a) PQ b) Plastocyanin
 c) NADP d) Water
33. Dark reaction takes place in
 a) Stroma b) Grana
 c) Matrix d) Thylakoid
34. Due to photorespiration, approximately _____ of photosynthetically fixed CO_2 is lost.
 a) 25% b) 50%
 c) 60% d) 80%
35. In dark reaction, the first compound to accept CO_2 is
 a) RuMP b) RuBP
 c) PGAL d) PGA
36. Which of the following is the first stable product of photosynthesis in Maize ?
 a) PGA b) PGAL
 c) PEPA d) OAA
37. Which of the following is immediately used to produce sugar and then starch in C_3 pathway?
 a) PGAL b) PGA
 c) OAA d) DPGA
38. How many Calvin cycles are required to produce one molecule of glucose?
 a) 3 b) 4
 c) 5 d) 6
39. How many $NADPH_2$ molecules are required to produce one glucose molecule?
 a) 8 b) 10
 c) 12 d) 14
40. Which of the following is a photochemical reaction?
 a) Light reaction b) C_3 pathway
 c) C_4 pathway d) CAM pathway
41. Which of the following is a biochemical reaction ?
 a) Light reaction
 b) Cyclic electron transfer
 c) Photolysis of water
 d) Dark phase
42. The first CO_2 acceptor in C_4 pathway is
 a) Pyruvic acid
 b) Phosphoenol pyruvic acid
 c) OAA
 d) Malic acid
43. Which of the following enzymes fix CO_2 in C_4 pathway ?
 a) RuBP carboxylase b) PEP carboxylase
 c) Both a) and b) d) PEP kinase
44. C_4 plants show
 a) Kranz anatomy b) Wreath anatomy
 c) Both a) and b) d) Mosaic anatomy
45. Photolysis of water is a characteristic feature of
 a) cyclic photophosphorylation
 b) non-cyclic photophosphorylation
 c) C_3 pathway
 d) C_4 pathway
46. NADP stands for
 a) Nicotinamide Adenine Diphospho Nucleotide
 b) Nicotinamide Adenine Dinucleotide Phosphate
 c) Nicotine Adenine Dinucleotide Phosphate
 d) Both a) and b)
47. Which of the following is not a 4_c compound in C_4 pathway ?
 a) RuBP b) OAA
 c) Malic acid d) Aspartic acid
48. If light is cut and CO_2 supply is continued, then which of the following substances will get disappeared from photosynthesizing algal cells?
 a) RuBP b) PGAL
 c) RUMP d) PGA
49. Which of the following factors is not limiting ?
 a) CO_2 concentration b) Light intensity
 c) Temperature d) Water

Answer Keys

1. c)	2. c)	3. d)	4. c)	5. b)	6. c)	7. c)	8. b)	9. c)	10. a)
11. b)	12. b)	13. b)	14. c)	15. a)	16. b)	17. c)	18. d)	19. b)	20. a)
21. a)	22. c)	23. c)	24. c)	25. c)	26. c)	27. d)	28. b)	29. a)	30. b)
31. b)	32. c)	33. a)	34. a)	35. b)	36. d)	37. a)	38. d)	39. c)	40. a)
41. d)	42. b)	43. c)	44. a)	45. b)	46. b)	47. a)	48. a)	49. d)	



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