CHAPTER 02

Photosynthesis in Higher Plants

In this Chapter...

- Chloroplast : The Site of Photosynthesis
- Pigments Involved in Photosynthesis
- Mechanism of Photosynthesis
- Light Reaction (The Photochemical Reaction)
- Dark Reaction (Biosynthetic Phase)
- Calvin Cycle (C_3-Pathway)
- The C_4-Pathway
- Factors Affecting Photosynthesis

All animals including human beings depend on plants for their requirement of food. Green plants can synthesise their own food (autotrophs), but all other organisms depend on them directly or indirectly for their food needs. Green plants carry out photosynthesis. It is a physio-chemical process by which they use the light energy (from sun) to manufacture organic compounds.

Photosynthesis is an important phenomenon due to the following two reasons

(i) It is the primary source of food on the earth.

(ii) It is responsible for the release of oxygen into the atmosphere by green plants.

Photosynthesis in plants requires chlorophyll, light and $\mathbf{CO_2}$. In the basic reaction of photosynthesis, water and carbon dioxide combine to form carbohydrates and molecular oxygen. This reaction is driven by light energy.

$$\mathbf{6CO_2 + 6H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light energy}} C_6H_{12}O_6 + 6O_2}$$

Chloroplast : The Site of Photosynthesis

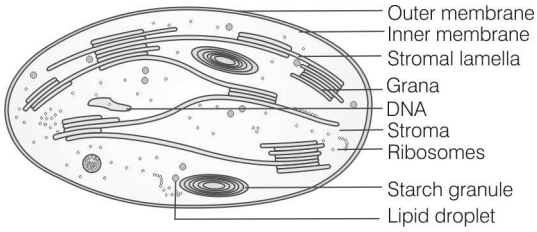
These are the green plastids that function as the site of photosynthesis, i.e. help in the synthesis of organic food. The process of photosynthesis takes place in the green leaves of the plants because chloroplasts are abundantly present in the mesophyll cell of the leaves.

Chloroplast aligned themselves with their flat surfaces parallel to the walls of the mesophyll cells under optimum light intensities and they are perpendicular to the walls of the mesophyll cells when the intensity goes very high, just to prevent photooxidation of chlorophyll-*a*.

Chloroplast is double membrane bound, DNA and ribosome containing semiautonomous cell organelle. Internally, a chloroplast contains a proteinaceous matrix or fluid called **stroma**, the membrane system called **lamellae** or **thylakoids**. At some places, the thylakoid gets aggregated to form stacks of discs, called **grana.**

The clear division of labour occurs within the chloroplasts, i.e. the membrane system is responsible for trapping of solar energy and the synthesis of ATP and NADPH (photochemical phase), whereas the stroma has enzymes, which are responsible for the reduction of carbon dioxide into carbohydrates and formation of sugars.

As the former set of reactions is dependent on light so they are called **light reactions**, while the latter is dependent on the products of light reactions, i.e. ATP and NADPH (and are independent from direct sunlight), thus are called **dark reactions**.



Diagrammatic representation of an electron micrograph of a section of chloroplast

Pigments Involved in Photosynthesis

The pigments involved in the process of photosynthesis are called **photosynthetic pigments**. These pigments provide different shades of green in the leaves in different plants or in the leaves of same plant.

These pigments can easily be separated out by chromatographic technique (paper chromatography). On the basis of their significance, the photosynthetic pigments are of two types

(i) **Primary Pigments** The pigment forms the main molecule of photosystem, e.g. chlorophyll- *a*, *b*.

(ii) **Accessory Pigments** These support the function of primary pigments, e.g. xanthophylls and carotenoids.

A chromatographic separation of the leaf pigments shows that it is not only the single pigment, which is responsible for the colour in the leaves. Instead different shades in leaves are due to four different pigments that have different ability to absorb **light at specific** wavelength.

Different pigments present in leaf are described below

(a) **Chlorophyll-*a* ($C_{55}H_{72}O_5N_4Mg$)** This is bright or blue-green in the chromatogram. It is known to be the chief plant pigment associated with photosynthesis.

(b) **Chlorophyll-*b* ($C_{55}H_{70}O_6N_4Mg$)** This is yellow-green in colour.

(c) **Xanthophylls** They are yellow in colour. These pigments are oxidised carotenoids.

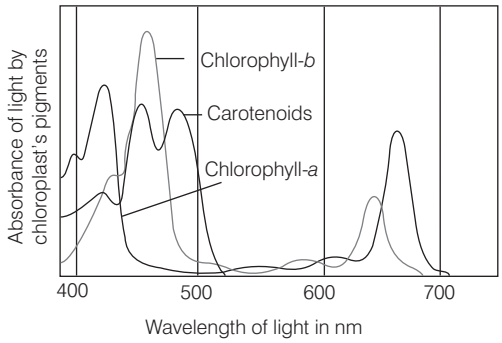
(d) **Carotenoids** They are yellow to yellow-orange in colour. They are also known as 'antenna pigment'.

Chlorophyll is the most abundant plant pigment found in the plants in the world. It contains magnesium (Mg^{2+}) metal as its constituent. Chlorophyll-*a* is found in all photosynthesising cells.

Absorption Spectrum

It is the curve that shows the **amount of different wavelength** of lights absorbed by a substance (photosynthetic pigment). The graph given below shows the ability of chlorophyll-*a* to absorb lights of different wavelengths.

Chlorophyll-*a* shows the maximum absorption peak at **450 nm** and also shows another peak at **650 nm**.

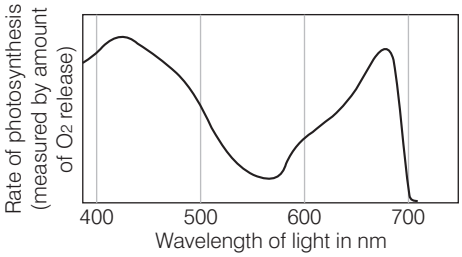


Graph showing the absorption spectrum of chlorophyll-*a, b* and the carotenoids

Absorption spectrum is constituted by the pigments like violet, blue, orange and red (400-500 and 600-700 nm) lights. The emission spectrum is constituted by yellow and yellow-green pigment (500-550 nm).

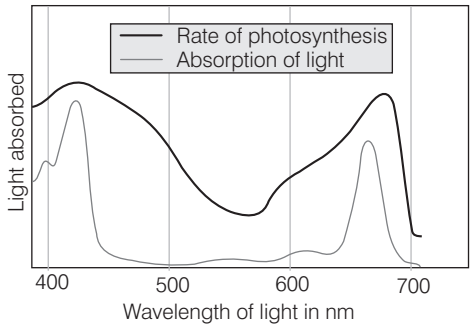
Action Spectrum

It is the curve that depicts the **relative rates** of photosynthesis at different wavelengths of light. Now, another graph given below, shows the wavelength at which maximum photosynthesis occurs at blue, violet and red wavelength in a plant (which is shown by chlorophyll-*a*).



Graph showing action specturm of photosynthesis

Hence, this concludes that chlorophyll-*a* is the chief pigment, which is majorly responsible for the photosynthesis. The another graph given below shows the action spectrum of photosynthesis, which coincide closely to the absorption spectrum of chlorophyll.



Superimposed on absorption spectrum of chlorophyll-*a*

All three graphs together shows that the major part of the photosynthesis takes place in the blue and red regions, while some of the photosynthesis takes place at other wavelengths also in the **visible spectrum**.

Apart from chlorophyll-*a* (the major pigment,) which is mainly responsible for trapping of light, other thylakoid pigments such as chlorophyll-*b*, xanthophylls and carotenoids also absorb light, transferring energy to chlorophyll-*a*. These pigments are called **accessory pigments**.

These pigments enable a wider range of wavelength of incoming light to be utilised for photosynthesis and also provide protection to chlorophyll-*a* from photooxidation.

Note ***Photosynthetically Active Radiation*** *(PAR) The region of wavelength in which photosynthesis takes place normally. It ranges from 400-700 nm.*

Mechanism of Photosynthesis

It was observed that the rate of photosynthesis is directly proportional to the intensity of light, i.e. rate increases with the increase in intensity of light till the plant achieves a **saturation point**.

The process of photosynthesis takes place in following two steps

Light Reaction
(The Photochemical Phase)

Light reaction includes the following steps, i.e. absorption of light, splitting of water, release of oxygen and finally the formation of high energy chemical intermediates, i.e. ATP and NADPH.

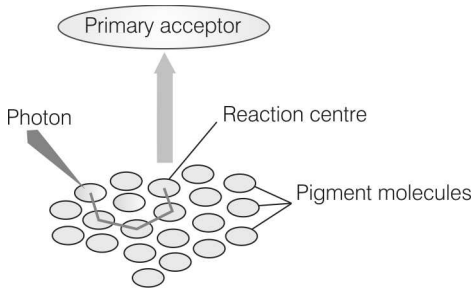
During the course of light reaction, light is trapped by photosynthetic pigments present in the **quantasomes** of grana thylakoids.

These photosynthetic pigments are organised into two discrete photochemical **Light Harvesting Complexes** (LHCs) known as **Photosystem-I** (PS-I) and **Photosystem-II** (PS-II).

Photosystems

The **light harvesting complexes** or **photosystems** are made up of hundreds of pigment molecules bounded by proteins. Each photosystem has a **photocentre** or **reaction centre**, where actual reaction takes place.

This reaction centre contains a special chlorophyll-*a* molecule. It is fed by hundred other pigment molecules and it forms the light harvesting system called **antennae**. These antennae molecule absorb light of different wavelength, but shorter than reaction centre in order to make photosynthesis more efficient.



The light harvasting complex

The reaction centre is different in both the photosystem as given below

(i) In PS-I, the reaction centre or chlorophyll-*a* has peak of absorption at 700 nm, known as P700.

(ii) In PS-II, the reaction centre has absorption peak at 680 nm hence, called P680.

Note *These photosystems are, named according to the sequence of their discoveries and not in the sequence in which they function during the light reaction.*

The Electron Transport

In PS-II, the chlorophyll-*a* absorbs 680 nm wavelength of red light, causing electrons to become excited and jump into another orbit.

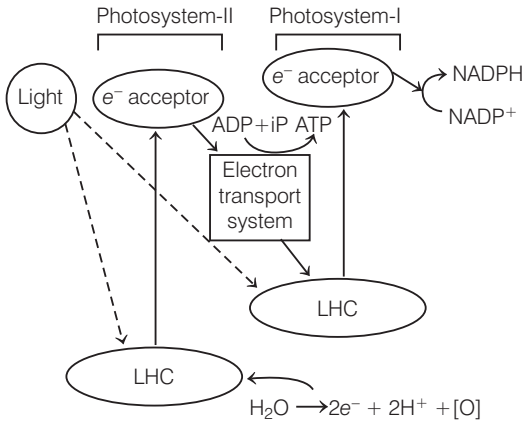
These electrons are picked up by an electron acceptor, which passes them to an **electrons transport system consisting of cytochromes**.

These electrons are not used up, but are passed on to the pigments of PS-I.

The electrons in the reaction centre PS-I are also excited when they receive red light of wavelength 700 nm and are transferred to another acceptor molecule.

These electrons move down hill to a molecule of energy rich $NADP^+$. The addition of these electrons reduces $NADP^+$ to $NADPH + H^+$.

This whole scheme of transfer of electrons, starting from PS-II, uphill to the acceptor and finally down hill to $NADP^+$ causing it to reduced to $NADPH + H^+$ is called **Z-scheme**, due to its characteristic shape.



Z-scheme of light reaction

Splitting of Water

PS-II supplies electrons continuously by splitting of water. Water is split into $2H^+$, [O] and electrons in the presence of light (i.e. photolysis). This creates oxygen, one of the net products of photosynthesis.

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

Photophosphorylation

Photophosphorylation is the process through which ATP is synthesised from ADP and inorganic phosphate (Pi) by the cell organelles (like mitochondria and chloroplasts) with the help of energy from solar radiation.

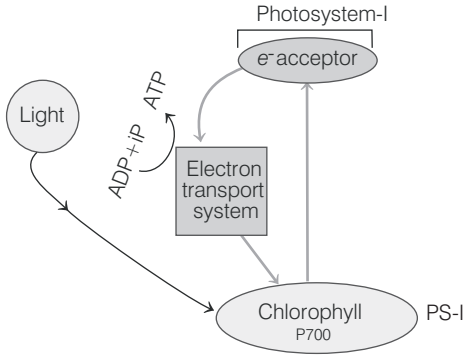
The process of photophosphorylation is of two types

(i) **Non-cyclic Photophosphorylation** It is a type of photophosphorylation in which both the photosystems (PS-I and PS-II) cooperate in light driven synthesis of ATP. During this cycle, the electron released from PS-II does not return back to it. Hence, it is known as non-cyclic photophosphorylation. Thus, both NADPH and ATP are formed during this reaction, are used in light independent reaction and are called **reducing power**.

(ii) **Cyclic Photophosphorylation** It is the type of photophosphorylation in which only PS-I is taking part and the electron released from the reaction centre P700 returns back to it after passing through a series of carrier, i.e. circulation takes within the photosystem and the phosphorylation occurs due to cyclic flow of electrons.

Note *When non-cyclic form of photophosphorylation gets stopped under certain conditions, the cyclic photophosphorylation keeps operating and photosynthesis continues for some time.*

The cyclic photophosphorylation takes place in the **stromal lamellae** of the chloroplast. This happens because the stromal lamellae do not possess enzyme, NADP reductase (essential for reducing $\mathbf{NADP^+}$ to NADPH) and PS-II. Thus, the excited electrons in the cyclic photophosphorylation does not pass on to $\mathbf{NADP^+}$ instead it gets cycled back to the PS-I complex.



Cyclic photophosphorylation

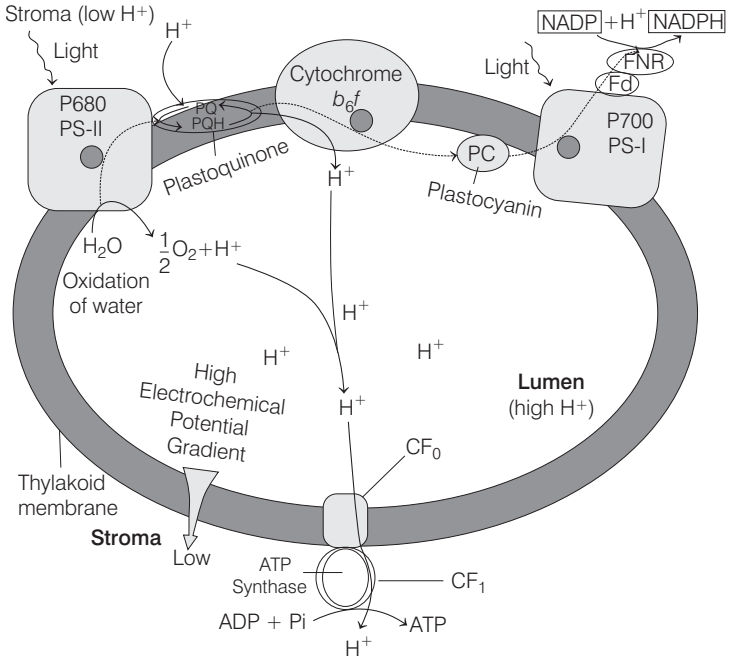
Chemiosmotic Hypothesis

It explains the mechanism of ATP synthesis in chloroplast. ATP synthesis is related to development of a proton gradient across a membrane.

The steps that cause a proton gradient to develop are

- The proton or hydrogen ions that are produced by splitting of water, accumulate within the lumen of thylakoids.
- As electrons move through the photosystems, protons are transported across the membrane. This is because the primary acceptor of electron, which is located towards the outer side of membrane transfers its electrons not to an electron carrier, but to H carrier. Hence, this molecule removes a proton from the stroma, while transporting an electron. The proton is then released into the inner side of the membrane.
- The NADP reductase enzyme is located on the stroma side of membrane. The protons are necessary for the reduction of $NADP^+$ to $NADPH + \mathbf{H^+}$. These protons are also removed from the stroma.
- Hence, within the chloroplast, protons in the stroma decreases in number, while in the lumen there is accumulation of protons. This creates a proton gradient across the thylakoid membrane.

- The breakdown of gradient provides enough energy to cause a change in $\mathbf{F_1}$-particle of the ATPase, which makes the enzyme to synthesise several molecules of energy packed ATP. ATPase enzyme catalyses the formation of ATP.
- The ATP is used immediately in biosynthetic reaction, taking place in stroma, responsible for fixing CO_2 and synthesis of sugar.



ATP synthesis through chemiosmosis

Dark Reaction (Biosynthetic Phase)

This phase does not require direct sunlight, but it depends on the products of the light reaction, i.e. ATP and NADPH beside $\mathbf{CO_2}$ and water that drive the processes leading to the synthesis of food more accurately, the sugars (glucose is the first product of photosynthesis).

Note *The O_2 thus, produced in the light reaction of the photosynthesis diffuses out of the chloroplast and is released into atmosphere.*

As soon as the light becomes unavailable, the biosynthetic process continues for some time and then eventually stops and starts again if the light is made available.

Originally, this process is known as **carbon-fixation** or **Photosynthetic Carbon Reduction** (PCR) cycle.

These reactions are sensitive to temperature change, but are independent of light, hence called **dark reaction**. This takes place in the stroma of chloroplast.

Thus, assimilation of $\mathbf{CO_2}$ during photosynthesis is of two main types

(i) **C_3-Pathway** This pathway is followed by the plants when first product of $\mathbf{CO_2}$-fixation is a $\mathbf{C_3}$ acid, i.e. PGA.

(ii) **C_4-Pathway** This pathway is followed or shown by the plants in which first product of $\mathbf{CO_2}$-fixation is a $\mathbf{C_4}$ acid, i.e. OAA.

Calvin Cycle (C_3 Pathway)

This is a cycle biochemical pathway of reduction of $\mathbf{CO_2}$ or photosynthetic carbon, cycle which was discovered by **Melvin Calvin in** 1950.

The Calvin cycle runs in all **photosynthetic plants**, no matter they show $\mathbf{C_3}$, $\mathbf{C_4}$ or any other pathway. It occurs in stroma of the chloroplast.

Primary Acceptor of CO_2 in C_3 Pathway

After a long research and conducting many experiments it was concluded by the scientists that in $\mathbf{C_3}$ pathway, the acceptor molecule is a 5-carbon ketose sugar, i.e. Ribulose 5-Bisphosphate (5 RuBP).

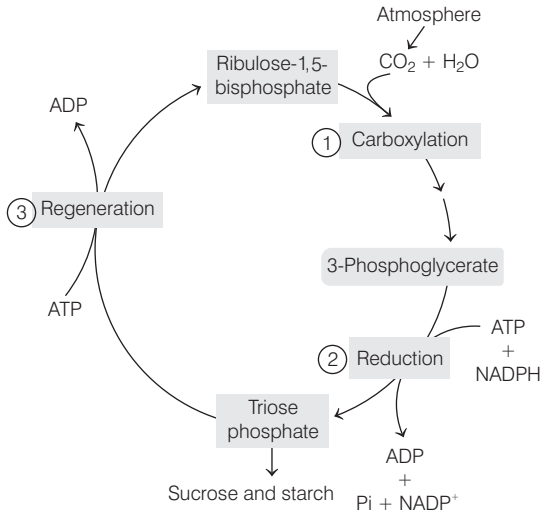
Calvin or $\mathbf{C_3}$ cycle has following three major steps

1. Carboxylation

It is the most crucial step of the Calvin cycle. In this, fixation of $\mathbf{CO_2}$ molecule takes place in the form of carboxylation of RuBP (5C). This reaction is catalysed by the enzyme **RuBP carboxylase**. This finally leads to the formation of two molecules of 3-Phosphoglyceric Acid (3PGA). As the RuBP carboxylase enzyme also has an activity of oxygenation.

Thus, it is more commonly known as **RuBP carboxylase-oxygenase** or **RuBisCO**.

$$\mathbf{CO_2 + RuBP + H_2O \xrightarrow[Mg^{2+}]{RuBisCO} 2\ (3\text{-PGA})}$$



Calvin cycle (C_3 pathway)

2. Reduction

After the carboxylation reaction, reduction of PGA takes place through a series of reactions leading to the formation of glucose. In this step, the ATP (as energy source) and NADPH (hydrogen atom carrier) are utilised. It is to be noted that 2 molecules of ATP and 2 molecules of NADPH are utilised in this step for phosphorylation and for the reduction of $\mathbf{CO_2}$, respectively. Hence, the fixation of 6 molecules of $\mathbf{CO_2}$ and 6 turns of the cycle are required in order to release one molecule of glucose from the pathway.

3. Regeneration

For the continuous and uninterrupted functioning of the Calvin cycle, there must be a regular supply of ATP, NADPH and also sufficient amount of RuBP is required. The regeneration of RuBP ($\mathbf{CO_2}$ acceptor) is a complex process and involves many types of sugar starting from triose (3C) to heptose (7C).

The regeneration step requires one ATP molecule for phosphorylation. Hence, for every $\mathbf{CO_2}$ molecule that enters the Calvin cycle, are required 3 molecules of ATP and 2 molecules of NADPH.

Note *The cyclic phosphorylation takes place in order to meet the difference in the number of ATP and NADPH used in the dark reaction.*

Thus, in order to produce one molecule of glucose through the Calvin pathway, 18 ATPs and 12 NADPHs are required.

This can be easily understood by the following table given below

In	Out
6 $\mathbf{CO_2}$	1 glucose
18 ATP	18 ADP
12 NADPH	12 NADP

The C_4-Pathway

$\mathbf{C_4}$-pathway is present in plants that are adapted to live in dry tropical regions.

These plants ($\mathbf{C_4}$-plants) have the $\mathbf{C_4}$ acid, i.e. oxaloacetic acid as the first $\mathbf{CO_2}$-fixation product. They use the $\mathbf{C_3}$-pathway or the Calvin cycle as the main biosynthetic pathway.

Characteristics of $\mathbf{C_4}$-plants

- They have a special type of leaf anatomy.
- They can tolerate high temperatures.
- They show a high light intensities.
- They lack a process called photorespiration and have greater productivity of biomass.

C_4-plants have **bundle sheath cells** in their leaves called as '**Kranz anatomy**'.

In Kranz anatomy, bundle sheath cells form several layers around the vascular bundles, having a large number of chloroplasts, thick walls impervious to gaseous exchange and no intercellular spaces.

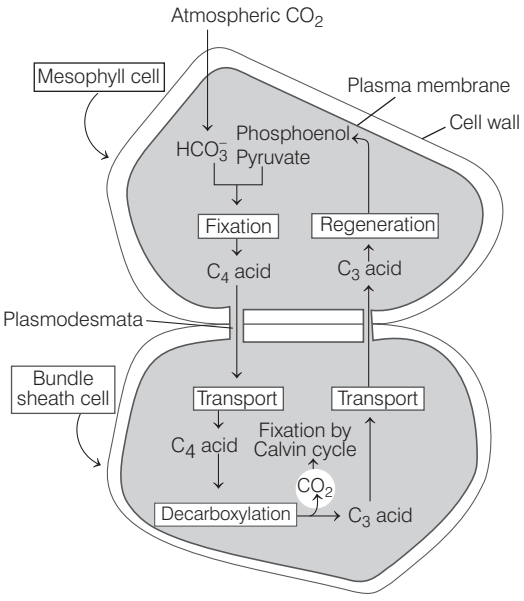
The Hatch and Slack pathway is also a cyclic process, which occurs in the following steps

Step I In $\mathbf{C_4}$-plants, the initial fixation of $\mathbf{CO_2}$ occurs in mesophyll cells. The primary acceptor of $\mathbf{CO_2}$ is **Phosphoenol Pyruvate** (PEP).

Step II It combines with $\mathbf{CO_2}$ in the presence of an enzyme, **phosphoenol pyruvate carboxylase** or **PEP carboxylase** (PEPCase) to form the first stable (a 4 carbon organic acid) product of $\mathbf{C_4}$ pathway, i.e. the Oxaloacetic Acid (OAA).

Step III The compound (OAA) are transported to the bundle sheath cells where they are broken down, releasing $\mathbf{CO_2}$ and a 3-carbon molecule.

Step IV The 3-carbon compound is again transported back to the mesophyll cells where regeneration of PEP takes place, thus completing the cycle.



Diagrammatic representation of the Hatch and Slack Pathway

The $\mathbf{CO_2}$ thus, released in the bundle sheath cells enters the $\mathbf{C_3}$ or the Calvin cycle (common pathway to all plants).

Photorespiration

It is a process, which creates an important difference between C_3 and C_4-plants.

It is a process which occurs in C_3-plants only.

- In this, O_2 binds to the RuBisCO and decreases CO_2 fixation.
- Then, RuBP binds with O_2 instead of forming PGA and form one molecule of phosphoglycerate and phosphoglycolate. This pathway is called **photorespiration**.
- In this pathway, there is neither synthesis of sugars nor of ATP. Rather, it results in release of CO_2 with the utilisation of ATP. So, photorespiration is a wasteful process here.

In C_4-plants, photorespiration does not occur, this is because they have a mechanism that increases the concentration of CO_2 at the enzyme site.

- C_4-acid from mesophyll cells is broken down in the bundle sheath cells to release CO_2. This results in increasing the intracellular concentration of CO_2.
- In turn, this ensures that the RuBisCO functions as a carboxylase, minimising the oxygenase activity.
- The C_4-plants lack photorespiration, that is why the productivity and fields are better in these plants.

Differences between C_3 and C_4-Plants

Characteristics	C_3-plants	C_4-plants
Cell type in which the Calvin cycle takes place	Mesophyll	Bundle sheath
Cell type in which initial carboxylation takes place	Mesophyll	Mesophyll
How many types of cells does the leaf have that fix CO_2	1; mesophyll	2; mesophyll and bundle sheath
Number of carbons in primary CO_2 acceptor	5	3
Primary CO_2-fixation product	3 Phosphoglyceric Acid (PGA)	Oxaloacetic Acid (OAA)
Numbers of carbons in primary CO_2-fixation product	3	4
Presence of RuBisCO	Yes	Yes
Presence of PEPCase	No	Yes
Cells having RuBisCO	Mesophyll	Bundle sheath
CO_2-fixation rate under high light conditions	No	Yes
Presence of photorespiration at low light intensities	No	No
Presence of photorespiration at high light intensities	Yes	No
Presence of photorespiration at low CO_2 concentration	Yes	No
Presence of photorespiration at high CO_2 concentration	No	No
Optimum temperature	20-25° C	30-40 ° C
Geographical location of plants	Present everywhere	In tropical climate
Examples	Mango and guava	Maize and sugarcane

Factors Affecting Photosynthesis

The rate of photosynthesis gets affected by many internal and external or environmental factors.

1. Internal Factors

These factors include number, size, age and orientation of leaves, mesophyll cells and chloroplasts, internal concentration of CO_2 and chlorophyll content.

2. External Factors

These factors generally include an environmental factor like availability of sunlight, temperature, concentration of CO_2 and water.

Hence, factors available at suboptimal levels help in determining the rate of photosynthesis at any point.

Concept of Limiting Factors

For a study of the above factors, it is essential to have knowledge of Blackman's law of limiting factors. This is because before 1905, early scientists attempted to determine the effect of individual factors on the photosynthetic rate in terms of minimum, optimum and maximum values which are known as cardinal points. The simultaneous effects of other factors, also has an importance in determining the rate of photosynthesis.

Blackman criticised the above said concept and stated that, when a process is controlled by more than one factor then the rate of the process is limited by the factor, which is nearest to its **minimal value** (is limited by the pace of the slowest factor).

For example, despite the presence of a green leaf and optimal light and CO_2 conditions, the plant may not photosynthesise till the moment the temperature is very low. But if the optimal temperature is provided again to this it will surely start photosynthesising.

Hence, if an increase of light beyond a certain limit or point occurs it causes the breakdown of chlorophyll and decrease in the rate of photosynthesis.

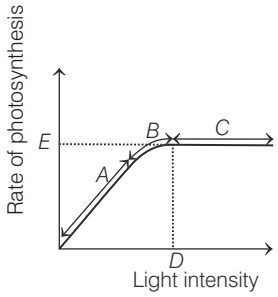
Some of the factors that affect the photosynthetic rate are discussed ahead in detail.

i. Light

The light provides the energy for photosynthesis. Thus, it is one of the major factors, which affect the rate of photosynthesis. Three characteristics of light, i.e. the intensity, quality and duration generally influences the rate. So, discussing the light as a factor that affects photosynthesis, two conditions are observed.

(a) At **low light intensities**, the linear relationship between incident light and rate of CO_2-fixation occurs.

(b) While at **higher intensity of light**, the rate fails to show further increase as the other factors become limiting (saturation point).



Graph of light intensity on the rate of photosynthesis

At 10% of full sunlight, the saturation of light occurs. Thus, excepting the shade and the dense forests, the light is a limiting factor in a very rare conditions in nature.

Note *If low light conditions are prevail, both C_3 and C_4-plants fail to respond to high CO_2 conditions, while at high light intensities, both show increase in the photosynthetic rates but upto a certain limit.*

ii. Carbon Dioxide Concentration

In C_4-plants also, the photosynthesis increases as the CO_2 concentration increases, but at much lower concentration of CO_2, these plants tend to attain saturation (around $360\ \mu L^{-1}$, while the C_3-plant becomes saturated at much higher CO_2) level (around $450\ \mu L^{-1}$). Thus, it concludes that the current availability of CO_2 levels is a limiting factor to the C_3-plants.

It has been demonstrated by the scientists itself that the C_3-plants can grow much faster and lead to higher productivity due to the higher rate of photosynthesis. Thus, in order to obtain higher yield some greenhouse crops like tomatoes, bell pepper, etc., are allowed to grow in atmosphere enriched with carbon dioxide.

iii. Temperature

Enzyme controlled dark reactions are affected by change in temperature. Photosynthesis occurs in a very wide range of temperature. The C_4-plants respond to a higher temperature showing higher rate of photosynthesis on the other hand, the C_3-plants have much lower optimum temperature range.

When temperature is increased from minimum to optimum, the rate of photosynthesis doubles for every 10°C rise in the temperature. But when the temperature reaches above optimum range the rate of photosynthesis shows initial increase for a very short duration of time which later gets declined.

Different plants have different optimum temperature range for photosynthesis. It depends on their habitat. The tropical plants have higher temperature range for photosynthesis than the temperature plants.

iv. Water

The effect of water as a factor is more on the plant as a whole rather than directly on photosynthesis. In water stress conditions, the **stomata** become closed which reduce the availability of CO_2 to plants, thereby causing reduction in the rate of photosynthesis.

Besides this the decrease in water availability causes leaves to **wilt** thus, reducing the surface area of the leaves ultimately reducing their **metabolic activity**.

Chapter Practice

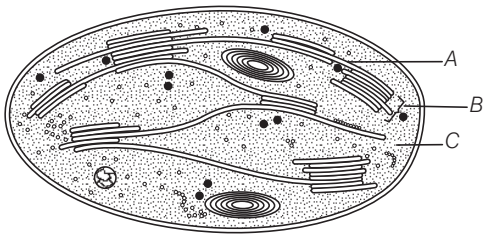
PART 1
Objective Questions

• Multiple Choice Questions

1. Photosynthesis is an essential process for life on earth because
(a) it is the primary source of all food on earth
(b) it is responsible for the release of the oxygen
(c) it is the only natural process responsible for the utilisation of sunlight
(d) All of the above

Ans. (***d***)

2. Identify *A*, *B* and *C* in given figure.



(a) *A*–Stroma wall, *B*–Granum, *C*–Stroma
(b) *A*–Stroma lamella, *B*–Granum, *C*–Stroma
(c) *A*–Stroma lamella, *B*–Stroma, *C*–Granum
(d) *A*–Stroma wall, *B*–Stroma, *C*–Granum

Ans. (***b***) A–Stroma lamella, *B*–Granum, *C*–Stroma

3. Which one of the following statements is incorrect about chloroplast ?
(a) Usually chloroplast align themselves along the walls of mesophyll cells, so that they get optimum quantity of incident light
(b) Within chloroplast there is a membranous system consisting of grana, stroma lamellae and stroma
(c) There is division of labour
(d) In grana, CO_2 is fixed

Ans. (***d***) Statement in option (d) is incorrect and can be corrected as
CO_2 is fixed during Calvin cycle in the stroma of chloroplast.

4. Match the following columns.

	Column I		Column II
A.	Chlorophyll-*a*	1.	Yellow
B.	Chlorophyll-*b*	2.	Bright or blue-green
C.	Xanthophyll	3.	Yellow or yellow-orange
D.	Carotenoids	4.	Yellow-green

Codes

	A	B	C	D		A	B	C	D
(a)	2	4	1	3	(b)	3	4	2	1
(c)	4	3	2	1	(d)	4	2	1	3

Ans. (***a***) A–2, B–4, C–1, D–3

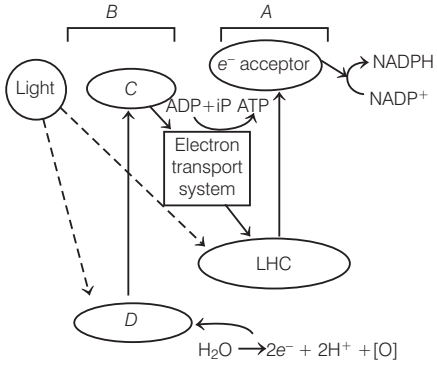
5. Light Harvesting Complexes (LHCs) are
(a) present within PS-I and PS-II
(b) very few molecule of chlorophyll-*a*
(c) hundred of pigment molecules bound to proteins
(d) Both (a) and (c)

Ans. (***d***) Both options (a) and (c) are correct.

6. The movement of electrons in Electron Transport System (ETS) in light reaction is
(a) uphill in terms of redox potential scale
(b) downhill in terms of redox potential scale
(c) uphill in terms of oxidation
(d) Both (a) and (b)

Ans. (***b***) The movement of electrons in ETS in light reaction is downhill in terms of an oxidation-reduction or redox potential scale.

7.



Which of the following is correctly labelled for the given figure?

(a) *A*–PS-II, *B*–PS-I, *C*– e^- acceptor, *D*–LHC
(b) *A*–LHC, *B*– e^- acceptor, *C*–PS-I, *D*–PS-II
(c) *A*–PS-I, *B*–PS-II, *C*–e^- acceptor, *D*–LHC
(d) *A*– e^- acceptor, *B*–LHC, *C*–PS-II, *D*–PS-I

Ans. (***c***) A–PS-I, *B*–PS-II, *C*–e^- acceptor, *D*–Light Harvesting Complex (LHC)

8. Read the following statements.

I. The electrons that carryout photophosphorylation are located in the thylakoid membrane.
II. During photophosphorylation, the chloroplast stroma becomes more acidic than the interior of thylakoid membrane.
III. Protons diffuse through the protein channels which are ATP synthetase molecules.
IV. ATP is formed from ADP + Pi on the stroma side of the thylakoid in the chloroplast.
V. During photophosphorylation, water ionises to form $\mathbf{H^+}$, yielding electrons to PS-II.

Which of the following above statements is/are false?

(a) I and II (b) III and IV
(c) IV and V (d) Only II

Ans. (***d***) Statement II is false and can be corrected as

During photophosphorylation, the chloroplast stroma is less acidic than the interior of thylakoid membrane because accumulation of protons during ETC occurs in the lumen of thylakoid.

Rest given statements are correct.

9. Consider the following statements.

I. During chemiosmotic synthesis of ATP, one ATP molecule is formed when $\mathbf{2H^+}$ pass through ATPase.
II. Light reaction of photosynthesis involve photochemical reactions.
III. Dark reaction of photosynthesis involve carbon reaction.
IV. Splitting of water takes place on the inner surface of the thylakoid membrane.

Choose the option containing correct statements.

(a) I, III and IV
(b) I, II and IV
(c) I, II, III and IV
(d) I, II and III

Ans. (***c***) All the given statements are correct.

10. Plants are divided into two groups based on the pathways they use for $\mathbf{CO_2}$ assimilation during biosynthetic phase of photosynthesis. These are

(a) $\mathbf{C_3}$-plants forming PGA and $\mathbf{C_4}$-plants forming OAA, respectively as first products of $\mathbf{CO_2}$-fixation
(b) $\mathbf{C_3}$-plants forming OAA and $\mathbf{C_4}$-plants forming PGA, respectively as first product of $\mathbf{CO_2}$-fixation
(c) $\mathbf{C_3}$-plants forming PEP and $\mathbf{C_4}$-plants forming OAA, respectively as first product of $\mathbf{CO_2}$-fixation
(d) None of the above

Ans. (***a***) $\mathbf{CO_2}$ assimilation during biosynthetic phase of photosynthesis was said to be of two main types, i.e.

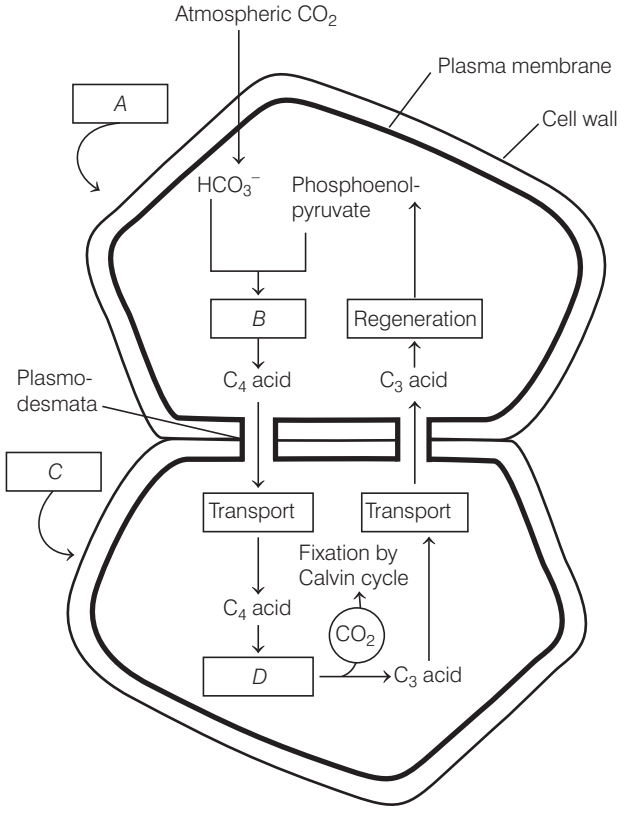
$\mathbf{C_3}$-plants in which first stable product of $\mathbf{CO_2}$-fixation is PGA ($\mathbf{C_3}$ acid) and $\mathbf{C_4}$-plants in which first stable product of $\mathbf{CO_2}$-fixation is OAA ($\mathbf{C_4}$ acid).

11. What is the site for $\mathbf{C_3}$-cycle in $\mathbf{C_3}$ and $\mathbf{C_4}$-plants?

(a) In $\mathbf{C_3}$-plants – Mesophyll cell and in $\mathbf{C_4}$-plants–Bundle sheath cell
(b) In $\mathbf{C_3}$-plants – Bundle sheath cell and in $\mathbf{C_4}$-plants–Mesophyll cell
(c) In $\mathbf{C_4}$-plants – Bundle sheath cells and in $\mathbf{C_3}$-plants–Bundle sheath cell
(d) In $\mathbf{C_3}$-plants – Mesophyll cell and in $\mathbf{C_4}$-plants–Mesophyll cell

Ans. (***a***) In $\mathbf{C_3}$-plants, all the reactions occur in mesophyll cells, while $\mathbf{C_4}$-plants show a distinct type of anatomy called as Kranz anatomy where both mesophyll cells and bundle sheath cells are involved.

12. Identify *A*, *B*, *C* and *D* in the given figure and choose the correct option accordingly.



(a) *A*–Mesophyll cell, *B*–Fixation, *C*–Bundle sheath cell, *D*–Decarboxylation
(b) *A*–Mesophyll cell, *B*–Decarboxylation, *C*–Bundle sheath cell, *D*–Fixation
(c) *A*–Chloroplast, *B*–Decarboxylation, *C*–Bundle sheath cell, *D*–Fixation
(d) *A*–Chloroplast, *B*–Fixation, *C*–Bundle sheath cell, *D*–Fixation

Ans. (***a***) *A*–Mesophyll cell, *B*–Fixation, *C*–Bundle sheath cell, *D*–Decarboxylation

13. Which of the following statements regarding photorespiration is/are true?
(a) It is a metabolically expensive pathway
(b) It is avoided when $\mathbf{CO_2}$ is abundant
(c) It results in a loss of usable carbon dioxide
(d) All of the above

Ans. (***d***) All the given statements are correct regarding photorespiration.

14. Match the following columns.

	Column I		**Column II**
A.	Oxygen evolving complex	1.	Potassium ferric oxalate
B.	Proton gradient	2.	High oxygen concentration
C.	Hill reaction	3.	ATP synthesis
D.	Photorespiration	4.	Pheophytin
		5.	Photolysis of water

Codes

	A	B	C	D
(a)	5	3	1	2
(b)	1	2	4	5
(c)	5	1	4	2
(d)	3	4	5	1

Ans. (***a***) A–5, B–3, C–1, D–2

15. Plant factors affecting photosynthesis include
(a) number, age, size and orientation of leaves, mesophyll cells and chloroplast, internal $\mathbf{CO_2}$ concentration and the amount of chlorophyll
(b) nature of leaves, size of mesophyll cell and light
(c) mesophyll cells distribution and temperature
(d) quantity of chlorophyll, size of leaves and $\mathbf{CO_2}$

Ans. (***a***) The rate of photosynthesis is important in determining the yield of plants including crop plants. Photosynthesis is under the influence of several factors, both internal (plant) and external. The plant factors include the number, size, age and orientation of leaves, mesophyll cells and chloroplast, internal $\mathbf{CO_2}$ and $\mathbf{O_2}$ concentration and the amount of chlorophyll.

• Assertion-Reasoning MCQs

Direction (Q. Nos. 1-5) *Each of these questions contains two statements, Assertion (A) and Reason (R). Each of these questions also has four alternative choices, any one of which is the correct answer. You have to select one of the codes (a), (b), (c) and (d) given below.*
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true, but R is not the correct explanation of A
(c) A is true, but R is false
(d) A is false, but R is true

1. **Assertion** (A) During photosynthesis, glucose is formed, but it is stored in the form of starch.
Reason (R) Glucose is osmotically active, while starch is inactive.

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

2. **Assertion** (A) PS-I and PS-II names are given on the basis of activity in the photosynthesis.
Reason (R) During non-cyclic photophosphorylation, PS-II works first and then PS-I.

Ans. (***d***) A is false, but R is true. A can be corrected as
The photosystem-I and photosystem-II are named in the sequence of their discovery and not in the sequence in which they function during the light reaction. During non-cyclic photophosphorylation, PS-II works first and then PS-I.

3. **Assertion** (A) Non-cyclic photophosphorylation occurs in the granum of chloroplasts.
Reason (R) There is discontinuous flow of electrons in this process.

Ans. (***c***) A is true, but R is false because
Non-cyclic photophosphorylation occurs in granum of chloroplast. It is an association of photosystems-I and II.
In this process, electrons continuously flow from water to PS-II then to PS-I and then finally to NADH.

4. **Assertion** (A) In $\mathbf{C_3}$-cycle, the first stable compound is 3C compound.
Reason (R) In $\mathbf{C_4}$-plants, Calvin cycle is absent.

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

In C_3-cycle, the first stable compound is 3C compound, the phosphoglycerate which is formed by the carboxylation of RuBP by one molecule of CO_2 in the presence of RuBP carboxylase.

In C_4-plants the first CO_2-fixation product is a 4C oxaloacetic acid, but they use C_3-pathway or Calvin cycle as the main biosynthetic pathway for carbon fixation (carboxylation), which occurs in the bundle sheath cells of leaves.

5. **Assertion** (A) Photorespiration is a waste process.

Reason (R) During photorespiration, neither ATP nor NADPH is formed.

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

• Case Based MCQ

Direction *Read the following passage and answer the questions that follows.*

During photosynthesis, light energy is converted into chemical energy in a multiprotein complex called photosystem. The thylakoid membrane contains two types of photosystems, *viz*., PS-I and PS-II and each of them consists of multiple antenna proteins containing chlorophyll molecules and other pigments. These pigments absorb light energy, so that the photosystems can carryout light-dependent or independent reactions.

(i) The products of light-dependent reactions are

(a) CO_2 and ATP

(b) NADPH, ATP and CO_2

(c) O_2, ATP and NADPH

(d) O_2 and $FADH_2$

Ans. (*c*) The products of light-dependent reactions are oxygen (O_2), ATP and NADPH.

(ii) PS-I functions when

(a) wavelength of light is higher than 680 nm

(b) NADPH accumulates

(c) CO_2-fixation is retarded

(d) All of the above

Ans. (*d*) All the listed factors are required for the functioning of PS-I.

(iii) PS-II transfers its electrons to

(a) chloroplast (b) mitochondria

(c) PS-I (d) None of these

Ans. (*c*) PS-II has the reaction centre of P680. It absorbs light energy and passes its electrons to the PS-I.

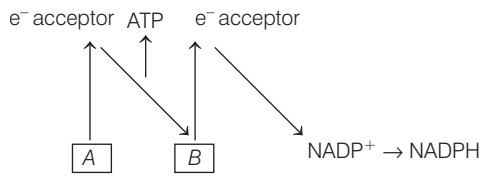
(iv) In PS-I, electrons come from

(a) splitting of water (b) ETC

(c) mitochondria (d) Either (a) or (b)

Ans. (*b*) In PS-I, electrons are derived from the Electron Transport Chain (ETC).

(v)



Identify the correct description about given diagram.

I. *A* and *B* represent P700 and P680, respectively.

II. Given process depicts oxidation/reduction changes during the light reaction of photosynthesis.

III. The given process was discovered by Bendall and Hill in 1960.

Choose the correct option.

(a) I, II and III (b) I and II

(c) II and III (d) I and III

Ans. (*c*) II and III are correct and I is incorrect. It can be corrected as

A and *B* represent P680 and P700, respectively.

PART 2

Subjective Questions

• Short Answer (SA) Type Questions

1. Mention any two reasons, which prove that photosynthesis is essential for sustaining life on the earth.

Ans Two reasons are as follows

(i) It is the process by which food is manufactured for all living organisms.

(ii) It is the only natural process by which oxygen is liberated into the atmosphere. This $\mathbf{O_2}$ is used by all living organisms respiring aerobically.

2. In tropical rainforests, the canopy is thick and shorter plants growing below it, receive filtered light. How are they able to carry out photosynthesis?

Ans The plant carry out photosynthesis in the presence of light. The light transmitted through the tree canopy is of low intensity light. Therefore, plants growing under the canopy of others have adapted themselves to carryout photosynthesis in low light intensities. The rate could be different depending upon the intensity and quantity of light received.

3. Explain the reasons of following

(i) Photosynthesis can occur in the absence of light.

(ii) Even non-green leaves can make the food.

(iii) Photosynthesis can occur under water.

Ans (i) Photosynthesis cannot occur in the absence of sunlight. The sunlight originally supplies the energy for conversion of $\mathbf{CO_2}$ to carbohydrate.

(ii) Yes, the chlorophyll is the most prominent plant pigment, but not in all plants. Some other accessory pigments such as xanthophylls and carotenoids can also perform photosynthesis separately (in some algae).

(iii) Photosynthesis can occur under water only when the water is clear and shallow. Some alga (Rhodophyta) can synthesise food at deep water layers as they can absorb the light of blue wavelength, efficiently.

4. Cyanobacteria and some other photosynthetic bacteria do not have chloroplasts. How do they conduct photosynthesis? **(NCERT Exemplar)**

Ans. The cyanobacteria and photosynthetic bacteria are prokaryotes. They do not have well defined membrane bound cell organelles but these organisms have photosynthetic pigments in a membranous form, which are primitive in nature but can trap and use solar energy. Their photosynthetic lamellae are suspended freely in the cytoplasm. So, they can carry out photosynthesis.

5. Describe how Engelmann arrived at the first action spectrum of photosynthesis.

Ans. **TW Engelmann** performed an interesting experiment with green alga, *Cladophora*. He splitted light into its **spectral components** by using prism. He then illuminated the alga placed in a suspension of aerobic bacteria *Rhodospirillum*. He noticed that the accumulation of bacteria was mainly in the region of the blue and red light of the split spectrum.

By the work done by him at first, action spectrum of photosynthesis was thus described, which roughly resembles the **absorption spectra** of chlorophyll-*a* and *b*.

6. Differentiate between stroma and grana of chloroplasts.

Ans. Differences between stroma and grana of chloroplasts are as follows

Stroma	**Grana**
It is the jelly-like matrix of the chloroplast.	These are formed of stacks of thylakoids.
Dark reaction takes place here.	Light reaction takes place here.

7. If a green plant is kept in dark with proper ventilation, can this plant carryout photosynthesis? Can anything be given as supplement to maintain its growth or survival? **(NCERT Exemplar)**

Ans. Plants need sunlight for photosynthesis. The sun is the only thing that will help plants make their own food. If there is a small opening in the room that let in sunlight however, the plant would grow towards the opening or the light to carryout photosynthesis and will survive.

8. Why is the colour of a leaf kept in the dark frequently becomes yellow or pale green? Which pigment do you think is more stable? **(NCERT)**

Ans. Since leaves require light to perform photosynthesis the colour of a leaf kept in the dark changes from a darker to a lighter shade of green. Some time it also turns yellow. This is due to the disintegration of chlorophyll pigment in continuous absence of light.

During this process, the xanthophyll and carotenoid pigments become predominant, causing the leaf to become yellow. These pigments are more stable as light is not essential for their production.

9. Give reasons for the following.

(i) Plants are the lungs of nature.

(ii) Chlorophyll-*b* and other accessory pigments are necessary for photosynthesis.

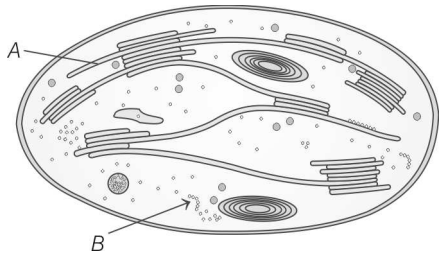
(iii) In the high light intensities, the chlorophyll-*a* gets damaged.

Ans. (i) Plants are also called lungs of the nature because, they perform the exact function as lungs do in mammals. They produce oxygen, which is necessary for all forms of life. So, in essence since our lungs keep us alive in the same way the trees keep our lungs alive. Thus, they are considered to be the part of our lung existence.

(ii) Chlorophyll-*b* and other accessory pigments are necessary as these are light absorbing compounds found in photosynthetic organisms. These pigments enable a wider range of wavelength of incoming light to be utilised for photosynthesis.

(iii) Chlorophyll-*a* structure is such that it gets damaged by bright/high light intensities. It is protected by carotenoid pigments.

10. Examine the figure



(i) This structure is present in animal cell or plant cell?

(ii) Can these be passed on to the progeny? How?

(iii) Name the metabolic processes taking place in the places marked *A* and *B*. **(NCERT Exemplar)**

Ans. (i) This structure present in plant cell.

(ii) Yes, these can be passed on to the progeny through female gametes.

(iii) In part *A* photophosphorylation and in part *B* Calvin cycle take place.

11. Which property of the pigment is responsible for its ability to initiate the process of photosynthesis? Why is the rate of photosynthesis higher in the red and blue regions of the spectrum of light?

Ans. The chlorophyll pigments are present in the thylakoid membranes. They have the property of excitability and emits $\mathbf{e^-}$ in the excited stage, though this $\mathbf{e^-}$ is replaced and transferred by the $\mathbf{e^-}$ generated from splitting of water molecules.

Red and blue light have maximum energy which a chlorophyll pigment absorbs and get excited and initiate the process of photosynthesis.

Also, its wavelength are 400-700 nm, i.e. between the Photosynthetic Active Radiation (PAR). Thus, the rate of photosynthesis is higher in blue and red light.

12. Suppose there were plants that had a high concentration of chlorophyll-*b*, but lacked chlorophyll-*a*, would it carry out photosynthesis? Also mention why do plants have chlorophyll-*b* and other accessory pigments? **(NCERT)**

Ans. Though chlorophyll-*a* is the major pigment responsible for trapping light. They act as antenna molecules and forms the reaction centres for both photosystems-I and II. Other photosynthetic pigments like chlorophyll-*b*, xanthophylls and carotenoids, which are called accessory pigments, also absorb light of different energy wavelengths and transfer their energy to chlorophyll-*a*. Indeed, they not only enable a wider range of wavelength of incoming light to be utilised for photosynthesis, but carotene protects chlorophyll-*a* from photo-oxidation. If any plant lack chlorophyll-*a* and contain a high concentration of chlorophyll-*b*, then this plant would not undergo photosynthesis.

13. Chlorophyll-*a* is the primary pigment for the light reaction. What are accessory pigments? What is their role in photosynthesis?

Ans. Accessory pigments are also photosynthetic pigments. These are chlorophyll-**b**, xanthophyll and carotenoids. These are not directly involved in emission of excited electrons, but they help in harvesting solar radiation and pass it on to chlorophyll-**a.**

This pigment itself absorbs maximum radiation at blue and red region. So, chlorophyll-*a* is the chief pigment of photosynthesis and others (i.e. chlorophyll-*b*, xanthophyll and carotenoids) are accessory pigments.

14. How are photosynthesis and respiration related to each other?

Ans. **Photosynthesis and respiration** are related, as in both mechanisms, the plants gain energy. In photosynthesis, plants gain energy from solar radiations whereas, in respiration, they breakdown glucose molecule to get energy in the form of ATP molecules.

They are related also because they are dependent on each other. The product of photosynthesis, i.e. glucose (food) is utilised in respiration to yield energy (ATP).

While doing so, it releases many other simple molecules ($\mathbf{CO_2 + H_2O}$) which are utilised in photosynthesis to produce more sugars.

15. What can we conclude from the statement that the action and absorption spectra of photosynthesis overlap? At which wavelength, do they show peaks? **(NCERT Exemplar)**

Ans. The absorption spectrum is the graph plotted, with the amount of light absorbed as a function of wavelength. The

action spectrum is the graph plotted with the rate of photosynthesis as a function of wavelength. Since, the amount of light absorbed and the rate of photosynthesis have a direct relationship, the two curves overlap. They show peaks around wavelengths 450 nm (blue region) and 650-680 nm (red region).

16. $2H_2O \rightarrow 2H^+ + 4e^- + O_2 \uparrow$

Based on the above equation, answer the following questions

(i) Where does this reaction take place in plants?

(ii) What is the significance of this reaction?

Ans. (i) Lumen of the thylakoids.

(ii) O_2 is evolved during this reaction, moreover electrons are made available to PS-II continuously.

17. Name the end products of light reaction of photosynthesis. Mention the fate of each of them.

Ans. ATP, NADPH and oxygen are the end products of light reaction.

ATP and NADPH are used in the reduction step of biosynthetic phase of photosynthesis. Oxygen is liberated into the atmosphere.

18. What are the important events and end products of the light reaction?

Ans. The important events of light reactions are

(i) Excitation of chlorophyll molecule to emit a pair of electrons and use of their energy in the formation of ATP from ADP + Pi. This process is called photophosphorylation.

(ii) Splitting of water molecule

(a) $2H_2O \longrightarrow 4H^+ + 4e^- + O_2 \uparrow$

(a) $NADP + 2H^+ \longrightarrow NADPH_2$

End products of light reaction are NADPH and ATP. Reducing power is produced in the light reaction, i.e. ATP and $NADPH_2$ molecules, which are used up in dark reaction. O_2 is evolved as a byproduct by the splitting of water.

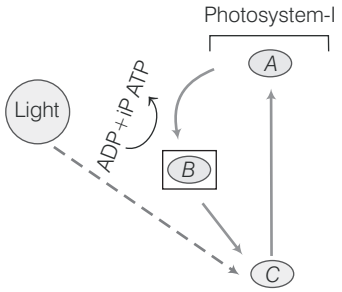
19. Dark reactions are dependent on light yet are called dark reactions. Justify.

Ans. Dark reactions are dependent on light but not directly rather it is dependent on the products of light reaction that are ATP and NADPH to carryout reduction of CO_2 to form glucose. This does not need light so, these are called dark reactions.

20. Cyclic photophosphorylation results in the production of ATPs and not NADPH. Give reasons.

Ans. Cyclic phosphorylation occurs when only 700 nm light is available and PS-I is functional. It occurs in the stroma lamellae where enzyme NADP reductase is absent and PS-II is also absent. Hence, electrons are passed on back to PS-I and not to $NADP^+$. So, the cyclic flow results in the formation of ATP, but not NADPH.

21. In the diagram shown below labels *A*, *B* and *C*. What type of phosphorylation is possible in this?



Ans. The diagram is showing cyclic photophosphorylation. Here, *A* is electron acceptor, *B* is electron transport system and *C* is photosystem-I or PS700.
In cyclic photophosphorylation, only PS-I is functional. The electron is circulated within the photosystem and the phosphorylation occurs due to cyclic flow of electrons.

22. Why is the lumen of thylakoids acidic while, the stroma is alkaline in nature?

Ans. The acidic nature of lumen of thylakoids is due to the accumulation of protons by the photolysis of water. The same reaction does not occur in stroma so, it is basic in nature.

23. Mention the four basic requirements for chemiosmosis to occur.

Ans. Four basic requirements are as follows

(i) A unit membrane (ii) A proton pump

(iii) A proton gradient (iv) ATP synthase enzyme

24. Expand RuBP and also mention the role of RuBP in photosynthesis.

Ans. RuBP is known as Ribulose 1, 5-Bisphosphate. It is the primary acceptor of carbon dioxide in Calvin cycle of C_3-plants. It forms the first stable compound of photosynthesis known as PGA.

25. ATPase enzyme consists of two parts. What are those parts? How are they arranged in the thylakoid membrane.

The conformational changes occur in which part of the enzyme?

Ans. ATPase enzyme consists of two parts, i.e. a stalk (F_0) and a headpiece (F_1). These two parts are located completely across the membrane of thylakoid. The conformational changes occur in the headpiece (F_1) of this enzyme.

26. Explain how during light reaction of photosynthesis, ATP synthesis as a chemiosmotic phenomenon takes place?

Ans. Chemiosmosis required a membrane, a proton pump, a proton gradient and ATP synthase enzyme. Energy is used to pump protons across a membrane, to create a gradient or a high concentration of protons within the thylakoid lumen. ATP synthase enzyme catalyses the formation of

ATP, along with the NADPH produced by the movement of electrons. The energy carried by ATP molecules will be used immediately in the biosynthetic reaction taking place in the stroma for fixing CO_2 and synthesis of sugars.

27. Where is NADP reductase enzyme located in the chloroplasts? What is the role of this enzyme in proton gradient development? **(NCERT Exemplar)**

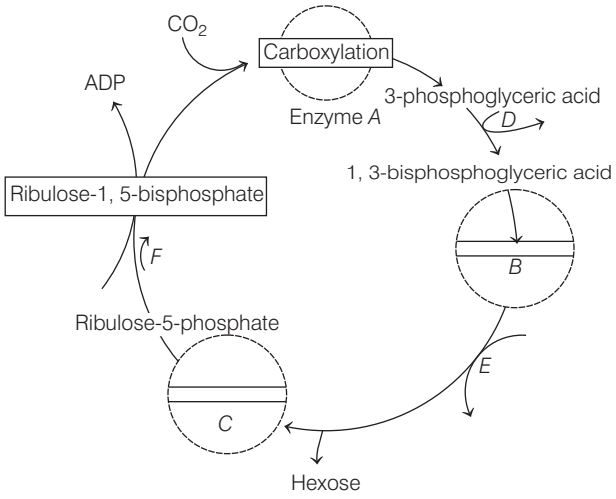
Ans. NADP reductase enzyme is located on the outer/stroma side of the thylakoid membrane. Along with the electrons from the primary acceptor of PS-I, it uses the protons of stroma for the reduction of $NADP^+$ to NADPH. This removal of protons from the stroma causes a proton gradient between the lumen of thylakoids and the stroma.

28. The diagram given below shows stages in the light-independent reactions of photosynthesis. Answer the following

(i) At which stage NADPH is oxidised?

(ii) What are **A**, **B** and **C**?

(iii) At what stages ATP is converted into ADP?



Ans. (i) NADPH is oxidised at stage *E*.

(ii) *A*–RuBP carboxylase oxygenase (RuBisCO), *B*–Reduction, *C*–Regeneration

(iii) ATP is converted to ADP at stages *D* and *F*.

29. Even though a very few cells in a C_4-plant carry out the biosynthetic Calvin pathway, yet they are highly productive. Can you discuss why?

Ans. C_4-plants chemically fix carbon dioxide in the cells of the mesophyll by adding it to the 3 molecules of Phosphoenol Pyruvate (PEP), a reaction catalysed by an enzyme called PEP carboxylase. It creates the 4 carbon organic acid, oxaloacetic acid. Oxaloacetic acid synthesised by this process is then translocated to specialised bundle sheath cells where the enzyme, RuBisCO and other Calvin cycle enzymes are located and where CO_2 released by decarboxylation of the 4 carbon acids is then fixed by RuBisCO enzyme to form 3-phosphoglyceric acids (3C).

The physical separation of RuBisCO from the oxygen driven light reactions inhibits photorespiration and increases CO_2-fixation. This way photosynthetic capacity of the C_4-plants increases many folds than C_2-plants.

30. What is the basis for designating C_3 and C_4 pathways of photosynthesis?

Ans. C_3-pathway or Calvin cycle represents phase-II, i.e. dark reaction of photosynthesis. In Calvin cycle, a 5C pentose sugar, Ribulose Bisphosphate (RuBP) acts as first acceptor of CO_2 whereas, the C_4-pathway is also called Hatch-Slack pathway in which, the first CO_2 acceptor is 3C Phosphoenol Pyruvate (PEP).

31. By looking at a plant externally, can you tell whether it is C_3 or C_4? Why and how?

Ans. The plants which are adapted to dry tropical regions have the C_4-pathway. However, the C_4-plants do not show any characteristic in external morphology. Unlike C_3-plants, the leaves of C_4-plants have a special anatomy called Kranz anatomy and this difference can only be observed at the cellular level. Therefore, it is difficult to say whether a plant is C_3 or C_4 by looking it only externally.

32. Give comparison between the C_3 leaf anatomy and C_4 leaf anatomy.

Ans. Comparison between anatomy of leaves in C_3 and C_4-plants are given below

C_3 Leaf Anatomy	C_4 Leaf Anatomy
Only one type of chloroplast is present.	Kranz anatomy, i.e. type of cell, each with its own type of chloroplast is present.
Less efficient in photosynthesis than C_4 leaves.	More efficient in photosynthesis than C_3 leaves.
Only mesophyll cells carryout photosynthesis.	Both mesophyll cells and bundle sheath cells carryout photosynthesis.

33. What conditions enable RuBisCO to function as an oxygenase? Explain the ensuring process.

Ans. RuBisCO possess an affinity for carbon dioxide and oxygen. In the presence of high carbon dioxide concentration the enzyme would effectively results in the formation of carboxylase. But in the presence of high concentration of oxygen, the enzyme would react and form oxygenase. This forces CO_2 to enter C_2-cycle, thus leading to photorespiration and loss of CO_2.

34. Why is RuBisCO enzyme the most abundant enzyme in the world?

Ans. The enzyme Ribulose-1, 5-bisphosphate carboxylase oxygenase, most commonly known by the shorter name RuBisCO is used in the Calvin cycle of photosynthesis to catalyse the first major step of carbon-fixation.

RuBisCO is thought to be the most abundant protein in the world since it is present in every plant that performs photosynthesis.

It makes about 20-25% of the soluble protein in the leaves and is made on the earth at the rate of about 1000 kg/s. It is estimated that every person on earth is supported by about 44 kg of RuBisCO.

35. In what kind of plants do you come across Kranz anatomy? To which conditions are those plants better adapted? How are these plants better adapted than the plants, which lack this anatomy?

Ans. C_4-plants are better adapted to dry tropical regions.

They have the following features

(i) Can tolerate high temperatures.

(ii) Can perform photosynthesis in high light intensities.

(iii) Have overcome the problem of photorespiration and have greater productivity of biomass.

36. Fill in the blanks at *A*, *B*, *C*, *D*, *E* and *F* and complete the $\mathbf{C_4}$-pathway/Hatch-Slack pathway.

Atmospheric $\mathbf{CO_2}$ enters *A*

↓

$\mathbf{CO_2}$ is accepted by *B* and forms four carbon acid compound *C*

↓

$\mathbf{C_4}$ acid enters into *D* and splits into $\mathbf{CO_2}$ and *E*

↓

$\mathbf{CO_2}$ enters Calvin cycle and 3C acid *F* is formed

Ans. *A*–Mesophyll cell, *B*–Phosphoenol Pyruvate (PEP), *C*–Oxaloacetic Acid (OAA), *D*–Bundle sheath cells, *E*–Pyruvate, *F*–Phosphoglyceric Acid (PGA).

37. A group of plants lacks photorespiration. Answer the following questions based on these plants.

(i) Which cells in the plant have RuBisCO?

(ii) Does photorespiration occur in these plants?

(iii) In which cells the $\mathbf{CO_2}$-fixation initially occurs?

Ans. (i) Bundle sheath cells in the plant have RuBisCO.

(ii) Photorespiration does not occur in these plants.

(iii) Atmospheric CO_2 is first fixed into organic acid (4C) in the mesophyll cells in the presence of PEP carboxylase enzyme.

38. Which of the following would not be a limiting factor in photosynthesis? Explain giving example.

(i) $\mathbf{CO_2}$ (ii) Oxygen

(iii) Light (iv) Chlorophyll

Ans. (iv) Chlorophyll would not act as a limiting factor in photosynthesis, e.g. sunloving plants contain less chlorophyll as compared to shadeloving plants, but the rate of photosynthesis in bright light is much higher in sunloving plants than is shadeloving plants.

39. Some of these terms/chemicals are associated with the $\mathbf{C_4}$-cycle. Explain.

(i) Hatch-Slack pathway

(ii) Calvin cycle

(iii) PEP carboxylase

(iv) Bundle sheath cells **(NCERT Exemplar)**

Ans. The terms associated with $\mathbf{C_4}$-cycle are

(i) **Hatch-Slack Pathway** The process of synthesis of glucose in $\mathbf{C_4}$-plants is different from $\mathbf{C_3}$-plants which was discovered by two scientists **MD Hatch** and **CR Slack** (1977). Hence, named Hatch-Slack pathway.

(ii) **Calvin Cycle** This cycle operates in bundle sheath cells and fixes $\mathbf{CO_2}$ to form glucose molecules.

(iii) **PEP Carboxylase** It is an enzyme present in mesophyll cells of $\mathbf{C_4}$-plants. It fixes $\mathbf{CO_2}$ to form 4-carbon compound, i.e. Oxalo Acetic Acid (OAA).

(iv) **Bundle Sheath Cells** These are specialised sclerenchymatous cells present around the vascular bundle, in the veins of monocot leaves. These have agranal chloroplast. $\mathbf{C_3}$-cycle occurs in these cells to manufacture glucose in $\mathbf{C_4}$-plants.

• Long Answer (LA) Type Questions

1. Is it correct to say that photosynthesis occurs only in leaves of a plant? Besides leaves, what are the other parts that may be capable of carrying out photosynthesis? Justify.

Ans. Although all cells in the green part of a plant have chloroplasts, most of the energy is captured in the leaves. The cells in the interior tissues of a leaf, called the mesophyll, can contain between 450000 and 800000 chloroplasts for every square millimeter of leaf (nearly 60-70 chloroplasts/cell).

The surface of the leaf is uniformly coated with a water-resistant waxy cuticle that protects the leaf from excessive evaporation of water and decreases the absorption of ultraviolet or blue light to reduce heating. The transparent epidermal layer allows light to pass through to the palisade mesophyll cells, where most of the photosynthesis takes place.

The green stems are also capable of performing photosynthesis.

2. The entire process of photosynthesis consists of a number of reactions. Name the part of the cell where following reactions take place.

(i) Synthesis of ATP and NADPH ..... .

(ii) Photolysis of water ..... .

(iii) Fixation of CO_2 ..... .

(iv) Synthesis of sugar molecule ..... .

(v) Synthesis of starch ..... .

Ans. (i) Synthesis of ATP and NADPH in thylakoids.

(ii) Photolysis of water occurs in inner side of thylakoid membrane in PS-II (680 nm).

(iii) Fixation of CO_2 occurs in stroma of chloroplast.

(iv) Synthesis of sugar molecule occurs in chloroplast.

(v) Synthesis of starch occurs in cytoplasm.

3. Give comparison between the cyclic and non-cyclic photophosphorylation. **[NCERT]**

Ans. Comparison between cyclic and non-cyclic photophosphorylation are as follows

Cyclic Photophosphorylation	**Non-cyclic Photophosphorylation**
It occurs in photosystem-I in stromal or intergranal lamellae.	It is carried out by both PS-I and PS-II in the granal thylakoids.
It is not connected to photolysis of water so no oxygen is evolved.	It is connected with photolysis of water, so oxygen is evolved in it.
It is activated by light of 700 nm wavelength.	It occurs in 680 nm as well as 700 nm wavelength.
It generates ATP only, there is no formation of $NADPH_2$.	It produces both ATP as well as $NADPH_2$.
Chlorophyll does not receive any electron from donor.	The source of electrons is photolysis of water.
The system does not take part in photosynthesis except in bacteria.	This system is connected with CO_2-fixation and is dominant in green plants.

4. Where does Calvin cycle take place in chloroplasts? Describe the three phases of Calvin cycle?

Ans. Calvin cycle occurs in bundle sheath cell of the chloroplast.

Calvin or C_3-cycle has many steps which are known as glycotic reversal or formation of sugar and takes place between reduction and regeneration. There are three major steps as follows

1. **Carboxylation** It is the most crucial step of the Calvin cycle. In this fixation of CO_2 molecule takes place in the form of carboxylation of RuBP (5C). This reaction is catalysed by the enzyme **RuBP carboxylase**. This finally leads to the formation of two molecules of 3 Phosphoglyceric Acid (3PGA). As the RuBP carboxylase enzyme also has an activity of oxygenation.
2. **Reduction** After the carboxylation reaction, reduction of PGA takes place through a series of reactions leading to the formation of glucose. In this step, the ATP (as energy source) and NADPH (hydrogen atom carrier) are utilised. It is to be noted that 2 molecules of ATP and 2 molecules of NADPH are utilised in this step for phosphorylation and for the reduction of CO_2, respectively.

   Hence, the fixation of 6 molecules of CO_2 and 6 turns of the cycle are required in order to release one molecule of glucose from the pathway.
3. **Regeneration** For the continuous and uninterrupted functioning of the Calvin cycle, there must be a regular supply of ATP, NADPH and also sufficient amount of RuBP is required. The regeneration of RuBP (CO_2 acceptor) is a complex process and involves many types of sugar starting from triose (3C) to heptose (7C).

   The regeneration step requires one ATP molecule for phosphorylation. Hence, for every CO_2 molecule that enters the Calvin cycle, are required 3 molecules of ATP and 2 molecules of NADPH.

5. A cyclic process is occurring in C_3-plant, which is light dependent and needs O_2. This process does not produce energy rather it consumes energy.

(i) Can you name the given process?

(ii) Is it essential for survival of the plant?

(iii) What are the end products of this process?

(iv) Where does it occur?

(v) Does it occur in C_4-plants also?

Ans. (i) Photorespiration.

(ii) No, it is not essential for survival of the plant.

(iii) Hydrogen peroxide.

(iv) The photorespiration occurs in chloroplast, peroxisomes and mitochondria.

(v) No, it does not occur in C_4-plants.

6. What special anatomical features are displayed by leaves of C_4-plants? How do they provide advantage over the structure of C_3-plants?

Ans. C_4-plants are special as they have a special type of leaf anatomy (Kranz anatomy) that can tolerate high temperatures and show a response to high intensities. Inspite of having Oxaloacetic Acid (OAA) as their first CO_2-fixation product, they use C_3-pathway or the Calvin cycle as the main photosynthetic pathway.

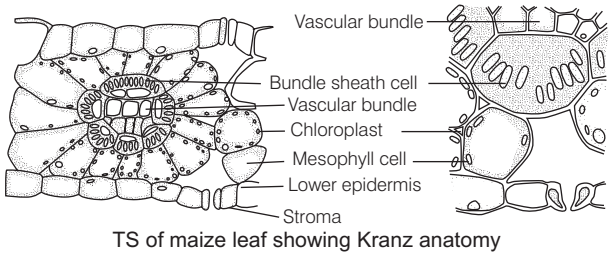
According to the structural leaf anatomy of C_3 and C_4- plants, the leaves of C_3-plants show only one type of cells called **mesophyll cells**, which contain only mesophyll chloroplast, while leaves of C_4-plants show two types of cells, i.e. outer mesophyll cells and inner spongy (which are large) cells around the vascular bundles called **bundle sheath cells** arranged in a circular manner.

It refers to the presence of two types of the chloroplast in the leaves. The mesophyll cells contain well-developed

granal chloroplast. They actively participate in light reaction. These produce ATP and NADPH_2.

The rudimentary chloroplasts are present in the cells of bundle sheath. They are agranal. The bundle sheath cells are mainly meant to carryout C_3-cycle.

This does not require well-developed chloroplast so, they are rudimentary lamellar type.



TS of maize leaf showing Kranz anatomy

The bundle sheath cells tend to form several layers around the **vascular bundles**.

They possess several special features such as

- Have large number of chloroplast.
- Thick walls which are impervious to gaseous exchange.
- There are no intercellular spaces.

7. RuBisCO is an enzyme that acts both as a carboxylase and oxygenase. Why do you think RuBisCO carries out more carboxylation in C_4-plants? **(NCERT)**

Ans. RuBisCO has a much greater affinity for CO_2 than for O_2 under normal conditions. It is the relative concentration of O_2 and CO_2 that determines which of the two will bind to the enzyme. In C_3-plants some O_2 does bind to RuBisCO and hence, CO_2-fixation is decreased. Here, the RuBP instead of being converted to 2 molecules of PGA binds with O_2 to form one molecule and phosphoglycolate in a pathway called photorespiration. In the photorespiratory pathway, there is neither synthesis of sugars, nor of ATP, rather it results in the release of CO_2 with the utilisation of ATP. In the photorespiratory pathway, there is no synthesis of ATP or NADPH. Therefore, photorespiration is a wasteful process.

In C_4-plants, photorespiration does not occur. This is because they have a mechanism that increases the concentration of CO_2 at the enzyme site. This takes place when the C_4 acid from the mesophyll is broken down in the bundle cells to release CO_2, this results in increasing the intracellular concentration of CO_2. In turn, this ensures that the RuBisCO functions as a carboxylase minimising the oxygenase activity.

8. Suppose *Euphorbia* and maize are grown in the tropical area.

(i) Which one of them do you think will be able to survive under such conditions?

(ii) Which one of them is more efficient in terms of photosynthetic activity?

(iii) What differences do you think are there in their leaf anatomy?

Ans. (i) *Euphorbia* will be able to survive under such conditions.

(ii) Maize is more efficient in terms of photosynthetic activity.

(iii) The maize in a C_4-plant having Kranz anatomy type of leaf anatomy. The bundle sheath cells are characterised by having a large number of chloroplasts, thick walls impervious to gaseous exchange and no intercellular spaces. While, *Euphorbia*, which undergoes CAM (Crassulacean Acid Metabolism) both pathways occur in mesophyll cells only they do not have Kranz anatomy. Also their stomata remain closed during the day.

• Case Based Questions

1. **Direction** *Read the following passage and answer the questions that follows*.

Vidhi attended the guest lecture on photosynthesis with her biology teacher. Guest for the seminar explained the basic functioning of chloroplast in the photosynthetic processes. As students from different schools attended the seminar. The guest for the lecture asked all students to put forward their queries regarding the topic. Vidhi stood up and asked him that, she is unable to understand the division of labour in the chloroplast. He appreciated her doubts and explained her about the same.

(i) What do you understand by the division of labour in chloroplast?

Ans. Division of labour appears clearly in the chloroplast, i.e. the membrane system is responsible for the synthesis of ATP and NADH. The dark reactions, i.e. reduction of CO_2 into carbohydrates and formation of sugar occur in the stroma of chloroplasts, where enzymes are present.

(ii) How the different pigments are involved in photosynthesis?

Ans. Various pigments are involved in photosynthesis like chlorophyll-*a* which acts as a chief pigment in photosynthesis and other pigments like chlorophyll-*b*, xanthophyll and carotenoids absorb light and transfer energy to chlorophyll-*a*. These pigments other than chlorophyll-*a* are called accessory pigments.

This pigment enable a wider range of wavelength of incoming light to be utilised for photosynthesis.

(iii) What is the significance of photosynthesis for animals?

Ans. The food in the form of starch is stored by plants in their parts like fruits, seeds, roots, stems and leaves, etc. All the animals depend on these plant products directly or indirectly. Hence, the photosynthesis in plants is very important for sustenance of all forms of life on earth.

(iv) Oxygen evolved during photosynthesis comes from H_2O or CO_2?

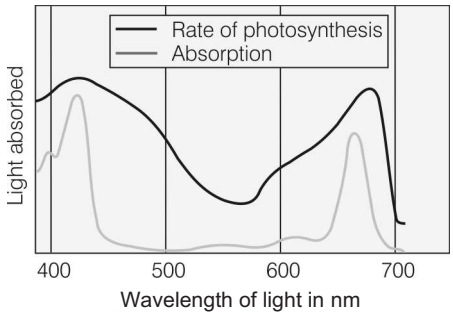
Ans. Oxygen in photosynthesis evolves from H_2O (i.e. by splitting of water) during light reaction.

(v) Photosynthetic pigments are located in which part of the chloroplast?

Ans. Photosynthetic pigments are located in the thylakoid membrane of the chloroplast.

2. In the figure given below, the black line (upper) indicates action spectrum for photosynthesis and the lighter line (lower) indicates the absorption spectrum of chlorophyll-*a*, answer the following.

(NCERT Exemplar)



(i) What does the action spectrum indicate?

Ans. It is the relative rates of photosynthesis at different wavelengths of light.

(ii) How can we derive an absorption spectrum for any substance?

Ans. Absorption of different wavelengths of light by a particular pigment is plotted and is called the absorption spectrum of that pigment.

(iii) If chlorophyll-*a* is responsible for light reaction of photosynthesis, why do the action spectrum and absorption spectrum not overlap?

Ans. Chlorophyll-*a* is responsible for light reaction of photosynthesis, but the action spectrum and absorption spectrum do not overlap because, though chlorophyll is the main pigment responsible for absorption of light, other thylakoid pigments like chlorophyll-*b*, xanthophylls and carotenoids, which are called accessory pigments, also absorb and transfer the energy to chlorophyll-*a*. Indeed they not only enable a wider range of wavelength of incoming light to be utilised for photosynthesis, but also protect chlorophyll-*a* from photo-oxidation.

3. **Direction** *Read the following passage and answer the questions that follows.*

Akshita who is a biology tutor was teaching photosystems to the students at her place. While explaining the topic light reaction said that, "Two of the three products of light reaction, ATP and NADPH are used to drive the reactions in the biosynthetic/dark phase." It has been verified by the fact that immediately after light becomes unavailable, the biosynthetic phase continues for some time and then stops; if light becomes available again, the process continues.

Her brother, student of class XI was also listening the same and was remembering that he had listened the same from his biology teacher also. He interupped her sister and asked her to re-explain the whole process for the better understanding.

(i) What are the products of light reaction?

Ans. Oxygen, ATP and NADPH are the products of light reaction.

(ii) Can we say that calling the biosynthetic phase, dark reaction is a misnomer? Justify.

Ans. Yes, calling biosynthetic phase a dark reaction is misnomer. This phase is not directly dependent on light, though it depends on the products of light reaction. It continues for some time, but when light becomes unavailable then it stops.

(iii) Name the first stable product of photosynthesis.

Ans. 3-Phosphoglyceric Acid (PGA) in C_3-plants and Oxaloacetic Acid (OAA) in C_4-plants are first stable products of photosynthesis.

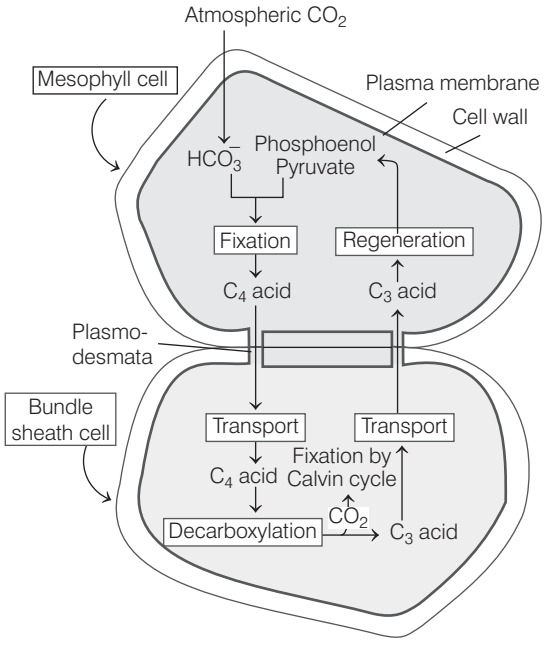
(iv) Why is proton gradient is important in photosynthesis?

Ans. Proton gradient is important as it makes energy available for ATP syntheisis.

(v) During dark phase of photosynthesis which is oxidised and which is reduced?

Ans. $NADPH_2$ is oxidised and CO_2 is reduced in dark phase of photosynthesis.

4. Observe the diagram and answer the following.



(i) Which group of plants exibit these two types of cells?

Ans. Monocot plants belonging to Graminae/Poaceae family, e.g. sugarcane, maize, etc., possess these two types of cells, i.e. bundle sheath and mesophyll cell (in Kranz anatomy).

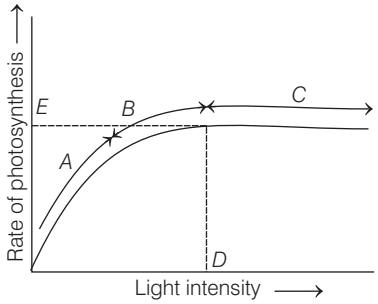
(ii) What is the first product of $\mathbf{C_4}$- cycle?

Ans. A 4-carbon compound oxaloacetic acid is the first product of $\mathbf{C_4}$- cycle.

(iii) Which enzyme is there in bundle sheath cells and mesophyll cells? **(NCERT Exemplar)**

Ans. Mesophyll cells have PEP carboxylase to fix atmospheric $\mathbf{CO_2}$ to form **a 4**-carbon compound oxalo acetic acid, whereas bundle sheath cells have RuBP carboxylase which fix $\mathbf{CO_2}$ by this enzyme to form 3-carbon compound 3 PGA (3 phosphoglyceric acid).

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



(i) At which point in the curve, light acts as a limiting factor?

Ans. Light is the limiting factor in region *A*. In the given graph, rate of photosynthesis initially increases with an increase in light intensity (region *A*).

(ii) What are characteristics of light which affect the rate of photosynthesis?

Ans. The light provides energy for photosynthesis. Thus, it is one of the major factors, which affects the rate of photosynthesis. Three characteristics of light, i.e. the intensity, quality and duration generally influences the rate.

(iii) At which condition linear relationship between incident light and rate of $\mathbf{CO_2}$-fixation is observed?

Ans. At low light intensities, the linear relationship between incident light and rate of $\mathbf{CO_2}$-fixation occurs.

(iv) What is the effect of green light in plants?

Ans. The green wavelength of light as low energy levels and is not useful for photosynthesis. So, if plants get exposure of green light for long, they may not carry out photosynthesis that might lead plant cell to starvation and death.

(v) Identify the incorrect statement.

Ans. If low light conditions prevail, both $\mathbf{C_3}$ and $\mathbf{C_4}$-plants fail to respond to high $\mathbf{CO_2}$ conditions, while at high light intensities both show increase in the photosynthetic rates but upto a certain limits.

Chapter Test

Multiple Choice Questions

1. The structures that are formed by stacking of organised flattened membranous sacs in the chloroplasts are
(a) grana
(b) stroma lamellae
(c) stroma
(d) cristae

2. Absorption spectrum of chlorophyll-*a* and the action spectrum of photosynthesis is identical because chlorophyll-*a*
(a) absorbs the maximum light
(b) absorbs the minimum light
(c) absorbs the red and blue light
(d) is found most abundantly

3. P700 is named because
(a) it is 700 times more efficient than other pigment molecules
(b) its absorption and action spectra show peaks at 700 nm
(c) it is rendered ineffective at wave length above 700 nm
(d) it is a unit consisting of 700 chlorophyll molecules

4. I. Cyclic photophosphorylation needs PS-I and PS-II.
II. Cyclic photophosphorylation produces NADPH + H^+ and ATP.
III. Cyclic photophosphorylation involves H_2O.
IV. Electrons are recycled in cyclic photophosphorylation.

Identify the correct and incorrect statements and select the option accordingly.
(a) I, II and III are incorrect, IV is correct
(b) I, II and IV are incorrect, III is correct
(c) I, III and IV are incorrect, II is correct
(d) II, III and IV are incorrect, I is correct

5. Consider the following statements.
I. H_2S not H_2O is involved in photosynthesis of sulphur bacteria.
II. ATP is produced during light reaction *via* chemiosmosis.
III. Absence of light leads to the stoppage of photosynthesis.
IV. Calvin cycle occurs in grana.

Choose the correct option.
(a) II, III and IV (b) I, III and IV
(c) I, II and IV (d) I, II and III

Assertion-Reasoning MCQs

Direction (Q. Nos. 1-3) *Each of these questions contains two statements, Assertion (A) and Reason (R). Each of these questions also has four alternative choices, any one of which is the correct answer. You have to select one of the codes (a), (b), (c) and (d) given below.*
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true, but R is not the correct explanation of A
(c) A is true, but R is false
(d) A is false, but R is true

1. **Assertion** (A) The absorption spectrum of chlorophyll-*a* shows close correlation with its action spectrum.
Reason (R) Both PS-I and PS-II contain chlorophyll-*a*.

2. **Assertion** (A) Calvin pathway of sugar synthesis is same in C_3 and C_4-plants.
Reason (R) C_3 is the only pathway for synthesis of sugar from CO_2.

3. **Assertion** (A) Lack of water indirectly decreases the rate of photosynthesis.
Reason (R) Lack of water causes wilting of leaves, which reduces their surface area.

Short Answer Type Questions

1. Photosynthetic organisms occur at different depths in the ocean. Do they receive the light? How do they adapt to carry out photosynthesis under these conditions? (**NCERT Exemplar**)

2. Two groups (*A* and *B*) or bean plants of similar size and same leaf area were placed in identical conditions. Group *A* was exposed to light of wavelength 400-450 nm and Group *B* to the light of wavelength of 500-550 nm. Compare the photosynthetic rate of the two groups by giving reason.

3. $3CO_2 + 9$ ATP + 6 NADPH + Water $\rightarrow$ Glyceraldehyde, 3-phosphate + 9 ADP + 6 NADP + 6 Pi.
Analyse the above reaction and answer the following questions.
(i) How many molecules of ATP and NADPH are required to fix one molecule of CO_2?
(ii) Where in the chloroplast does this process occur?

4. Name the two important enzymes of C_3 and C_4 pathways, respectively? What important role do they play in fixing CO_2?

5. How does water stress affect/decrease the rate of photosynthesis?

Long Answer Type Questions

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

2. Under what conditions are C_4-plants superior to C_3?

Answers

Multiple Choice Questions

***1.** (a)* ***2.** (c)* ***3.** (b)* ***4.** (a)* ***5.** (d)*

Assertion-Reasoning MCQs

***1.** (b)* ***2.** (a)* ***3.** (a)*