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PHOTOSYNTHESIS

SYLLABUS

Photosynthesis as a means of Autotrophic nutrition; Site of photosynthesis take place; pigments involved in Photosynthesis (Elementary idea); Photochemical and biosynthetic phases of photosynthesis; Cyclic and non cyclic and photophosphorylation; Chemiosmotic hypothesis; Photorespiration C3 and C4 pathways; Factors affecting photosynthesis.

KEY CONCEPTS

INTRODUCTION

* Photosynthesis is a photo-biochemical process (anabolic, endergonic and reductive) in which organic compounds (carbohydrates) are synthesised from the inorganic raw material (H_2O & CO_2) in presence of light & pigments. O_2 is evolved as a by product.
* Light energy is conserved into chemical energy by photosynthesis.

$$6CO_2 + 12H_2O \xrightarrow[\text{Light}]{\text{Pigment}} C_6H_{12}O_6 + 6O_2\uparrow + 6H_2O$$

Oxidation/light reaction

Reduction/dark reaction

* 90% of total photosynthesis is carried out by aquatic plants.
* First true & oxygenic photosynthesis started in cyanobacteria. (BGA)

HISTORICAL BACKGROUND

* Before seventeenth century it was considered that plants take their food from the soil.
* **Stephen Hales** (Father of Plant Physiology) (1727) reported that plants obtain a part of their nutrition from air and light may also play a role in this process.
* **Joseph Priestley** (1770) With his experiment on bell jar he concluded that plants purify air and gaseous exchange occurs during photosynthesis.
* **Jan Ingen-Housz** (1779) concluded by his experiment that purification of air was done by green parts of plant only and that too in the presence of sunlight. Green leaves and stalks liberate dephlogisticated air (Having O_2) during sunlight and phlogisticated air (Having CO_2) during dark. He showed that it is only the green part of the plants that could release oxygen.
* **Jean Senebier** discovered that green plants utilize carbon dioxide. It was thus a great land mark in the discovery of photosynthesis.
* **N.T. de Saussure** proved that the volume of carbon dioxide consumed is equal to the volume of oxygen liberated. He also showed that water is essential requirement in photosynthesis.
* **Pelletier** and **Caventou** named the green coloured substance in the leaves as **chlorophyll**.
* **F.F. Blackman** observed that the process of photosynthesis has two steps : a photochemical reaction which proceeds only in the presence of light and a dark reaction for which light is not necessary. Besides this, he also proposed the **law of limiting factor**.

* **Warburg** performed **Flashing experiment** on *Chlorella*.
* **Emerson** and **Arnold**, with the help of experiments determined that the light reaction of photosynthesis has two distinct photochemical processes.
* **Red drop and Emerson's enhancement effect:** Robert Emerson noticed a sharp decrease in quantum yield at wavelength greater than 680 nm, while determining the quantum yield of photosynthesis in chlorella using monochromatic light of different wavelengths.
  Since this decrease in quantum yield took place in the red part of the spectrum, the phenomenon was called as red drop.
  Later, they found that the inefficient far-red light beyond 680 nm could be made fully efficient if supplemented with light of shorter wavelength (blue light).
  The quantum yield from the two combined beams of light was found to be greater than the sum effects of both beams used separately.
  This enhancement of photosynthesis is called as Emerson's Enhancement.
* **Robert Hill's** experiment on *Stellaria media* demonstrated that in the presence of sunlight, water and a suitable hydrogen acceptor, isolated chloroplasts release oxygen, even if carbon dioxide is absent. This experiment is considered to be equivalent to light reaction. **Hill's oxidants are hydrogen acceptors**. The common ones are ferricyanide, benzoquinone and dichlorophenol indophenol (DCPIP), while $NADP^+$ is natural H^+ acceptor in photosynthesis.
* **Julius Von Sachs** (1854) demonstrated that first visible product of photosynthesis is starch. He also showed that chlorophyll is confined to the chloroplasts.
* **T.W Engelmann** (1843 – 1909). Described action spectrum of photosynthesis with the help of a green alga, *Cladophora*.
* **Cornelius van Niel** (1897-1985), who, based on his studies of purple and green bacteria, demonstrated that photosynthesis is essentially a light-dependent reaction in which hydrogen from a suitable oxidisable compound reduces carbon dioxide to carbohydrates.

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

In green plants H_2O is the hydrogen donor and is oxidised to O_2. Some organisms do not release O_2 during photosynthesis. When H_2S, instead is the hydrogen donor for purple and green sulphur bacteria, the 'oxidation' product is sulphur or sulphate depending on the organism and not O_2. Hence, the O_2 evolved by the green plant comes from H_2O, not from carbon dioxide. This was later proved by using radioisotopic techniques.

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

where $C_6H_{12}O_6$ represents glucose. The O_2 released is from water; this was proved using radio isotope techniques.

* **Ruben, Hassid** and **Kamen** using radioactive oxygen (O^{18}) confirmed that the source of oxygen in photosynthesis is water.
* **Melvin Calvin** (1954) traced the path of carbon in photosynthesis (Associated with dark reactions) and gave the C_3 cycle (Now named Calvin cycle). He was awarded Nobel prize in 1961 for the technique to trace metabolic pathway by using radioactive isotope.
* **M.D. Hatch** and **C.R. Slack** discovered a new series of reactions involved in photosynthetic CO_2 assimilation in many tropical plants. In these plants, the first stable compound in photosynthetic process is a 4-carbon compound, hence, this series of reactions is known as C_4 cycle.
* **Hill and Bendall** proposed the scheme of light reaction.
* **Huber et. al.** studied three dimensional structure of reaction center of bacteria *Rhodopseudomonas viridis* and got Nobel prize.

SITE OF PHOTOSYNTHESIS

* Occurs in Green parts of the plant (mainly in leaves but also in green stems & sepals of flower).
* Cells of green part contain chloroplast, a cell organelle which is actually involved in carrying out photosynthesis. (site of photosynthesis in cell).

* Chloroplast are green plastids which function as the site of photosynthesis in eukaryotic photoautotrops.

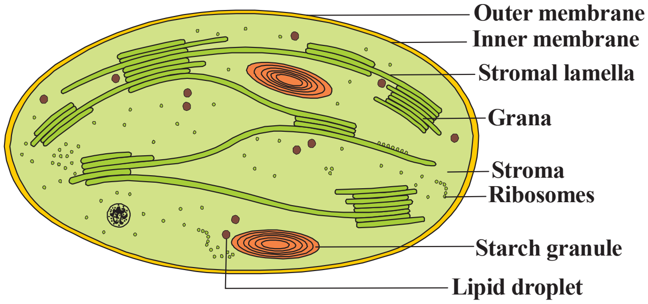


Figure : Diagrammatic representation of an electron micrograph of a section of chloroplast.

* Within the chloroplast there is the membranous system consisting of grana, the stroma lamellae, and the fluid stroma.
* There is a clear division of labour within the chloroplast. The membrane system is responsible for trapping the light energy and also for the synthesis of ATP and NADPH.
* In stroma, enzymatic reactions synthesise sugar, which in turn forms starch. The former set of reactions, since they are directly light driven are called **light reactions** (photochemical reactions).
* The latter are not directly light driven but are dependent on the products of light reactions (ATP and NADPH). Hence, to distinguish the latter they are called, by convention, as **dark reactions** (carbon reactions).
* Photosynthetic unit can be defined as number of pigment molecules required to affect a photochemical act, that is the release of a molecule of oxygen. Park and Biggins (1964) gave the term quantasome for photosynthetic units which is equivalent to 230 chlorophyll molecules.

Photosynthetic pigments

* Pigments are the organic molecules that absorb light of specific wavelengths in the visible region due to presence of conjugated double bonds in their structures.
* The chloroplast pigments are fat soluble and are located in the lipid part of the thylakoid membranes.

There is a wide range of chloroplastic pigments which constitute more than 5% of the total dry weight of the chloroplast.

* A chromatographic separation of the leaf pigments shows that the colour of the leaves is due to four pigments: **Chlorophyll a** (bright or blue green in the chromatogram), **chlorophyll b** (yellow green), **xanthophylls** (yellow) and **carotenoids** (yellow to yellow-orange).
* **Chlorophyll a** is the chief pigment associated with photosynthesis.
* The chlorophyll-a has a empirical formula as $C_{55}H_{72}O_5N_4Mg$. The molecule is distinguishable into a '**head**' of size 15 × 15 Å and a '**tail**' of 20 Å length. The 'head' is made up of **porphyrin**, (a tetrapyrrole closed ring derivative) and the 'tail' of **phytol** ($C_{20}H_{39}OH$). There is a 5^{th} isocyclic ring of **cyclopentanone**. A non-ionic magnesium atom is held within tetrapyrrole ring by two covalent and two co-ordinate bonds. There is vinyl group at carbon-2 position and methyl at carbon-3. The chlorophyll-a absorbs violet blue and red wavelengths of the spectrum giving peaks at 430 and 662 nm respectively. It is found in all photosynthetic organisms **except** bacteria. **Photochlorophyll is its precursor**.
* **Chlorophyll-b :** Its empirical formula is $C_{55}H_{70}O_6N_4$ Mg. It is similar to chlorophyll a except in having formyl (CHO) group instead of methyl (CH_3) at carbon-3 position of the tetrapyrrole ring. It absorbs blue and orange wavelengths giving peaks at 430 and 644 nm.
* **Chlorophyll-c** : It **lacks phytol esterification**. It is found in brown algae, diatoms and dinoflagellates.
* **Chlorophyll-d** : It has formyl group at carbon-2 position. It is reported from red algae.
* **Chlorophyll-e** : It has been reported from Xanthophyceae members like *Vaucheria.*
* **Bacteriochlorophyll** : The molecular formula of bacteriochlorophyll-a is $C_{55}H_{74}O_6N_4$ Mg. Its structure is similar to chlorophyll-a except presence of acetyl group instead of vinyl at carbon-2 position.
* **Chlorobium chlorophyll** : It has hydroxy-methyl group (CH_3CHOH) at carbon-2 position in the tetrapyrrole nucleus.

* Carotenoids absorb light energy and transfer it to Chl. *a* and thus act as accessory pigments. They protect the chlorophyll molecules from photo-oxidation by picking up nascent oxygen and converting it into harmless molecular stage. Carotenoids can be classified into two groups namely carotenes and xanthophyll.
* **Carotenes :** They are orange red in colour and have general formula $C_{40}H_{56}$. They are isolated from carrot.

  They are found in all groups of plants i.e., from algae to angiosperms. Some of the common carotenes are α, β, γ and δ carotene; phytotene, lycopene, neurosporene etc. The lycopene is a red pigment found in ripe tomato and red pepper fruits. The β-carotene on hydrolysis gives vitamin A, hence the carotenes are also called provitamin A. β-carotene is black yellow pigment of carrot roots.
* **Xanthophylls :** They are yellow coloured carotenoid also called xanthols or carotenols. They contains oxygen also along with carbon and hydrogen and have general formula $C_{40}H_{56}O_2$.
* Carotenoids have at least two major roles in photosynthetis :

(i) They transfer the light energy absorbed by them to chlorophyll molecules, hence are called **antenna molecules**. They absorb light in blue violet range and

(ii) They protect plant from excessive heat and prevents photo-oxidation (oxidative destruction by light) of chlorophyll.

* Blue-green algae have more quantity of phycocyanin and red algae have more phycoerythrin. Phycocyanin and phycoerythrin together form phycobilins. These water soluble pigments are thought to be associated with small granules attached with lamellae. Like carotenoids, phycobilins are accessory pigments *i.e.,* they absorb light and transfer it to chlorophyll *a*.
* Only visible spectrum of light (400 nm-700 nm) is utilized by Plants in photosynthesis. Therefore it is called as **PAR (Photosynthetically active radiation).**
* Graph plotted between amount of light absorbed by photosynthetic pigments and different wavelengths of visible spectrum (white light) is called as **absorption spectrum.**
* Graph plotted between rate of photosynthesis (measured by O_2 released) and different wavelength of visible spectrum is called as **action spectrum.**
* Action spectrum of photosynthetic pigments was studied by Engleman on *Cladophora* and *Spirogyra* for the first time.

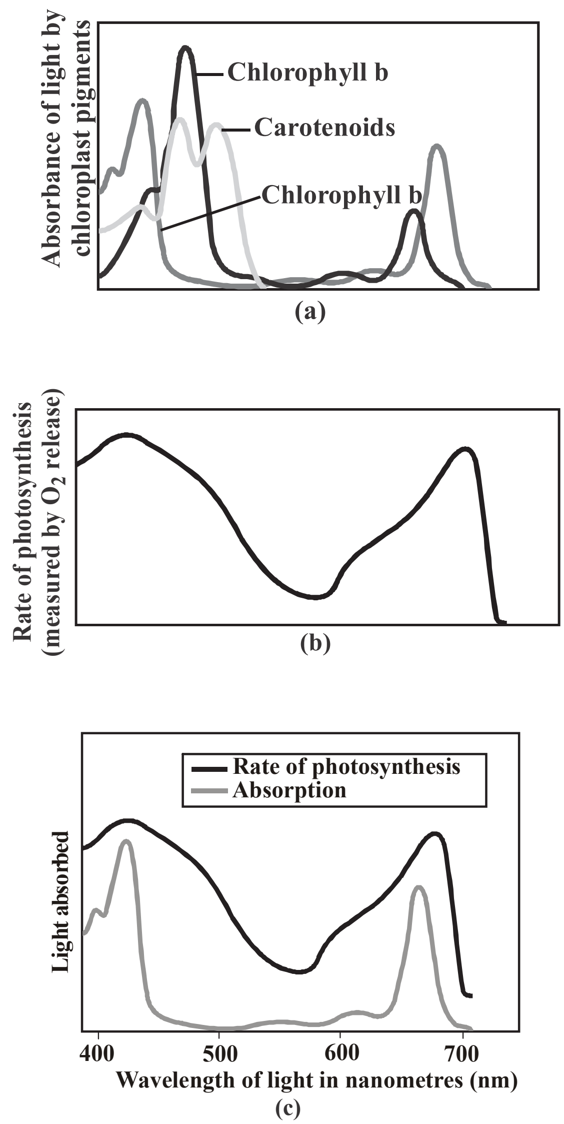


Figure : (a) Graph showing the absorption spectrum of chlorophyll a, b and the carotenoids. (b) Graph showing action spectrum of photosynthesis. (c) Graph showing action spectrum of photosynthesis superimposed on absorption spectrum of chlorophyll a.

LIGHT REACTION OR HILL REACTION

* Light reactions or the 'Photochemical' phase include light absorption, water splitting, oxygen release, and the formation of high-energy chemical intermediates, ATP and NADPH.
* Occurs in grana.
* The pigments are organised into two discrete photochemical light harvesting complexes (LHC) within the Photosystem I (PS I) and Photosystem II (PS II). These are named in the sequence of their discovery, and not in the sequence in which they function during the light reaction.

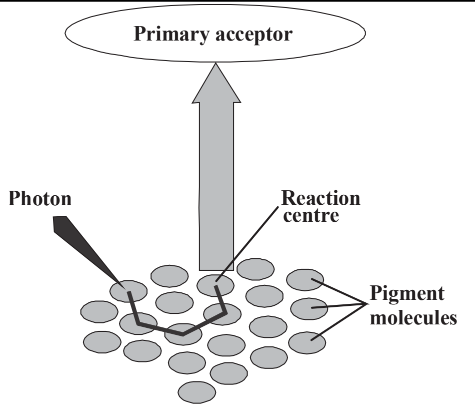
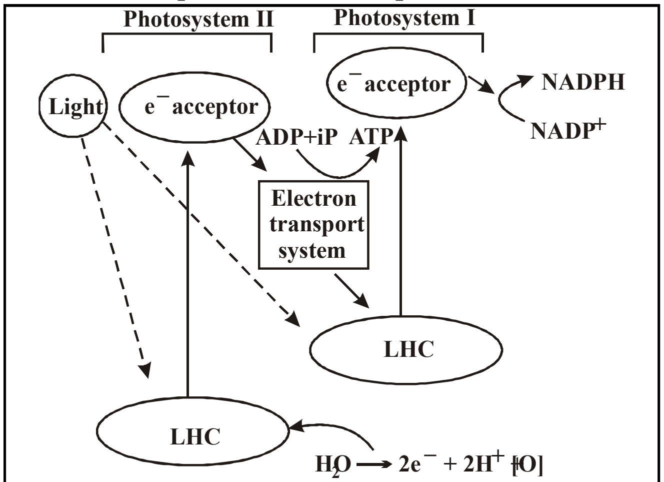


Figure : The light harvesting complex

* The LHC are made up of hundreds of pigment molecules bound to proteins. Each photosystem has all the pigments (except one molecule of chlorophyll a) forming a light harvesting system also called **antennae**. These pigments help to make photosynthesis more efficient by absorbing different wavelengths of light. The single chlorophyll a molecule forms the **reaction centre**. The reaction centre is different in both the photosystems.
* In PS I the reaction centre chlorophyll **a** has an absorption peak at 700 nm, hence is called **P700**, while in PS II it has absorption maxima at 680 nm, and is called **P680**.
* Pigment systems I and II are involved in non-cyclic electron transport, while pigment system I is involved only in cyclic electron transport. Photosystem I generates strong reductant NADPH. Photosystem II produces a strong oxidant that forms oxygen from water.
* During the light reaction, the primary function of the two pigment systems/photosystems is to interact with each other to trap light energy and convert it into the chemical energy (ATP). These reactions are cyclic and non cyclic types.

The electron transport :

* In photosystem II the reaction centre chlorophyll a absorbs 680 nm wavelength of red light causing electrons to become excited and jump into an orbit farther from the atomic nucleus.
* These electrons are picked up by an electron acceptor which passes them to an electrons transport system consisting of cytochromes.
* This movement of electrons is downhill, in terms of an oxidation-reduction or redox potential scale.
* The electrons are not used up as they pass through the electron transport chain, but are passed on to the pigments of photosystem PSI.
* Electrons in the reaction centre of PS I are also excited when they receive red light of wavelength 700 nm and are transferred to another acceptor molecule that has a greater redox potential.
* These electrons then are moved downhill again, this time to a molecule of energy-rich $NADP^+$. The addition of these electrons reduces $NADP^+$ to $NADPH + H^+$. This whole scheme of transfer of electrons, starting from the PS II, uphill to the acceptor, down the electron transport chain to PS I, excitation of electrons, transfer to another acceptor, and finally down hill to $NADP^+$ causing it to be reducing it to $NADPH + H^+$ is called the **Z scheme**, due to its characterstic shape. This shape is formed when all the carriers are placed in a sequence on a redox potential scale.



Z-scheme of light reaction

Splitting of Water :

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

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

* The water splitting complex is associated with the PS II, which itself is physically located on the inner side of the membrane of the thylakoid.

Cyclic and Non-cyclic Photo-phosphorylation:

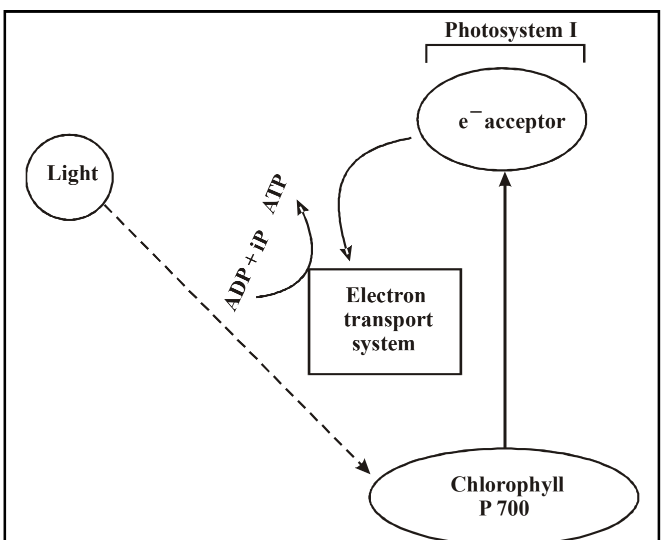
* Synthesis of ATP molecules in chloroplast from ADP & inorganic phosphate (Pi) using light energy is called as Photophosphorylation. It is of two types

(a) Non-cyclic

* Occurs due to unidirectional/non-cyclic electron transport.
* Both PS II & PS I are involved.
* The two photosystems are connected through an electron transport chain, as in the Z scheme. Both ATP and NADPH + H^+ are synthesised by this kind of electron flow.
* It occurs at grana thylakoids only.

(b) Cyclic :

* Occurs due to cyclic electron transport (same electron returns back to reaction centre of PS I).
* Only PS I is involved.
* Only ATP is produced.
* Occurs in the stroma lamellae.



Cyclic photophosphorylation

* The membrane or lamellae of the grana have both PS I and PS II the stroma lamellae membranes lack PS II as well as NADP reductase enzyme. The excited electron does not pass on to $NADP^+$ but is cycled back to the PS I complex through the electron transport chain. The cyclic flow hence, results only in the synthesis of ATP, but not of NADPH + H^+.
* Cyclic photophosphorylation also occurs when only light of wavelengths beyond 680 nm are available for excitation.

Chemiosmotic hypothesis:

* Chemiosmotic hypothesis was first explained by P. Mitchell.
* An explanation for mechanism of ATP synthesis due to electron transport during light reaction.
* ATP synthesis is linked to development of a proton gradient across a membrane of the thylakoid..
* The proton accumulation is towards the inside of the membrane, i.e., in the lumen.
* The proton gradient across the membrane is due to

(a) The splitting of the water molecule takes place on the inner side of the membrane, the protons or hydrogen ions that are produced by the splitting of water accumulate within the lumen of the thylakoids.

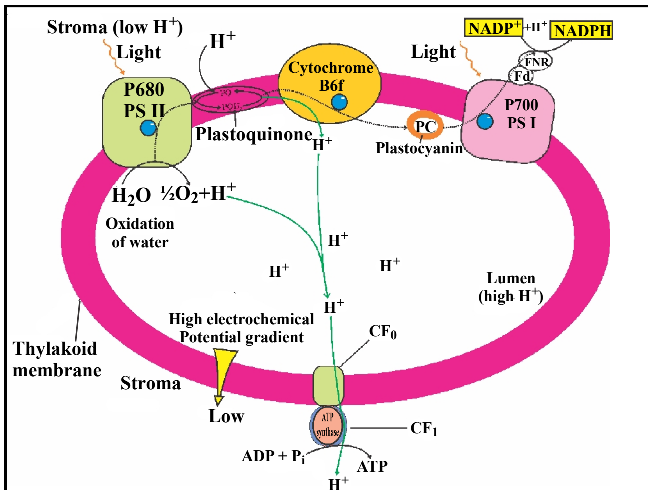


Figure : ATP synthesis through chemiosmosis

(b) As electrons move through the photosystems, protons are transported across the membrane. This happens because the primary acceptor of electron which is located towards the outer side of the membrane transfers its electron not to an electron carrier but to an H carrier.

Hence, this molecule removes a proton from the stroma while transporting an electron. When this molecule passes on its electron to the electron carrier on the inner side of the membrane, the proton is released into the inner side or the lumen side of the membrane.

(c) The NADP reductase enzyme is located on the stroma side of the membrane. Along with electrons that come from the acceptor of electrons of PS I, protons are necessary for the reduction of $NADP^+$ to $NADPH + H^+$. These protons are also removed from the stroma.

* Within the chloroplast, protons in the stroma decrease in number, while in the lumen there is accumulation of protons. This creates a proton gradient across the thylakoid membrane as well as a measurable decrease in pH in the lumen.
* The breakdown of proton gradient leads to synthesis of ATP. The gradient is broken down due to the movement of protons across the membrane to the stroma through the transmembrane channel of the CF_0 of the ATP synthase.
* The ATP synthase enzyme consists of two parts: one called the CF_0 is embedded in the thylakoid membrane and forms a transmembrane channel that carries out facilitated diffusion of protons across the membrane.
* The other portion is called CF_1 and protrudes on the outer surface of the thylakoid membrane on the side that faces the stroma.
* The break down of the gradient provides enough energy to cause a conformational change in the CF_1 particle of the ATP synthase, which makes the enzyme synthesise several molecules of energypacked ATP.
* Chemiosmosis requires a membrane, a proton pump, a proton gradient and ATP synthase.
* 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 has a channel that allows diffusion of protons back across the membrane; this releases enough energy to activate ATP synthase enzyme that catalyses the formation of ATP. Along with the NADPH produced by the movement of electrons, the ATP will be used immediately in the biosynthetic reaction taking place in the stroma, responsible for fixing CO_2, and synthesis of sugars.

DARK REACTION OR BLACKMAN REACTION

* The products of light reaction are ATP, NADPH and O_2.
* Of these O_2 diffuses out of the chloroplast while ATP and NADPH are used to drive the processes leading to the synthesis of food, more accurately, sugars. This is the **biosynthetic phase** of photosynthesis.
* This process does not directly depend on the presence of light but is dependent on the products of the light reaction, i.e., ATP and NADPH, besides CO_2 and H_2O.
* Occurs in stroma.
* With the help of radioactive ^{14}C in algal photosynthesis Melvin Calvin prove that the first CO_2 fixation product was a 3-carbon organic acid.
* There are two different pathways of CO_2 fixation occurring in different plants.

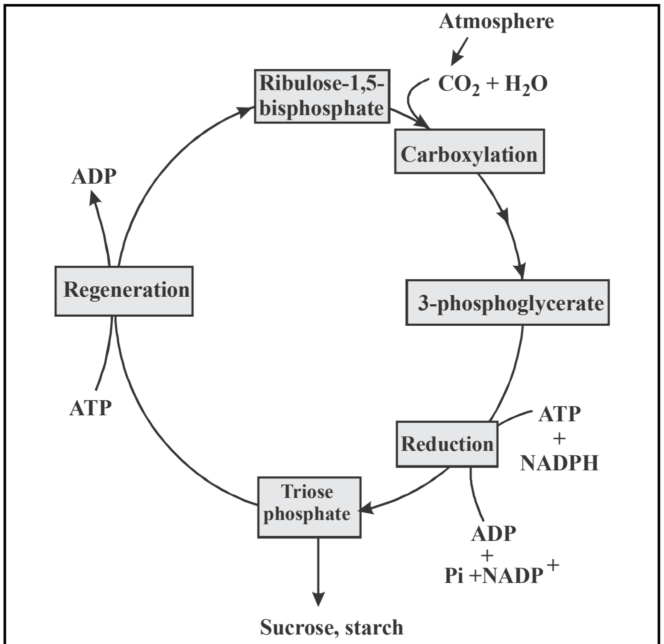
(i) Calvin cycle or C_3 Cycle

* Discovered by Melvin Calvin, Benson and Bassham in chlorella and scendesmus.
* First stable product is 3-carbon compound hence called C_3 cycle and plants having this pathway of CO_2 fixation are called as **C_3 plants.**
* It occurs in following three steps

(a) Carboxylation, in which CO_2 combines with primary acceptor called RUBP (ribulose 1,5 bisphosphate) in the presence of enzyme RUBISCO (Ribulose, 1.5 bisphosphate carboxylase oxygenase) to produce two molecules of PGA (Phosphoglyceric acid).

(b) Reduction, in which 2 molecules of PGA get reduced to 2 molecules of PGAL (Phosphoglyceraldehyde, triose sugar) using 2ATP and 2 NADPH.

(c) Regeneration, in which again primary acceptor (RUBP) is synthesized from PGAL & ATP.



Calvin Cycle

* What goes in and what comes out of the Calvin cycle.

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

(ii) C_4 Cycle or Hatch & Slack Pathway :

* Why C_4 pathway?

- In C_3 plants RUBISCO, an enzyme used in CO_2 fixation is very much sensitive to relative Concn. of CO_2 & O_2 in the chloroplast.
- At higher CO_2 Concn. behaves as carboxylase and at higher O_2 Concn.behaves as oxygenase.
- Since light reaction releases O_2, hence its concn. rises up.Thus RUBISCO starts behaving as oxygenase and binds RUBP with O_2 instead of CO_2 resulting in no synthesis of sugars.
- To avoid this some plants evolved a new mechanism i.e. C_4

* Discovered by Hatch & Slack, so called as Hatch & Slack Pathway.

* First stable product is 4- carbon compound (Oxaloacetic acid) hence called C_4-cycle and plants having this cycle are called as C_4 plants.

* C_4 plants have special kind of leaf anatomy called as **"Kranz anatomy"** (Presence of two types of photo-synthetic cells, i.e. mesophyll cells and bundle sheaths cells).

* In C_4 plants (Maize, sugar cane etc.) both C_3 cycle (In bundle sheath cell chloroplasts) & C_4 cycle (In mesophyll cell chloroplasts) occurs.

Mesophyll cell chloroplasts :

* Calvin cycle enzymes are absent.

* Concentrically arranged, form most of the leaf tissues.

* PS II present.

* Are granal (have grana), light reaction takes place, O_2 evolution occurs.

* Have phosphoenol pyruvate (PEP) as primary CO_2 acceptor, and PEP carboxylase enzyme for CO_2 fixation (not sensitive to O_2 Concentration).

Bundle sheath cell chloroplasts :

* Are agranal (lacks grana), hence no light reaction, no O_2 evolution.

* Absence of PS II.

* Receives only CO_2 due to decarboxylation of malic acid, hence high CO_2 Concentration is maintained to carry out CO_2 fixation by **Ribulose bisphosphate carboxylase-oxygenase (RuBisCO).**

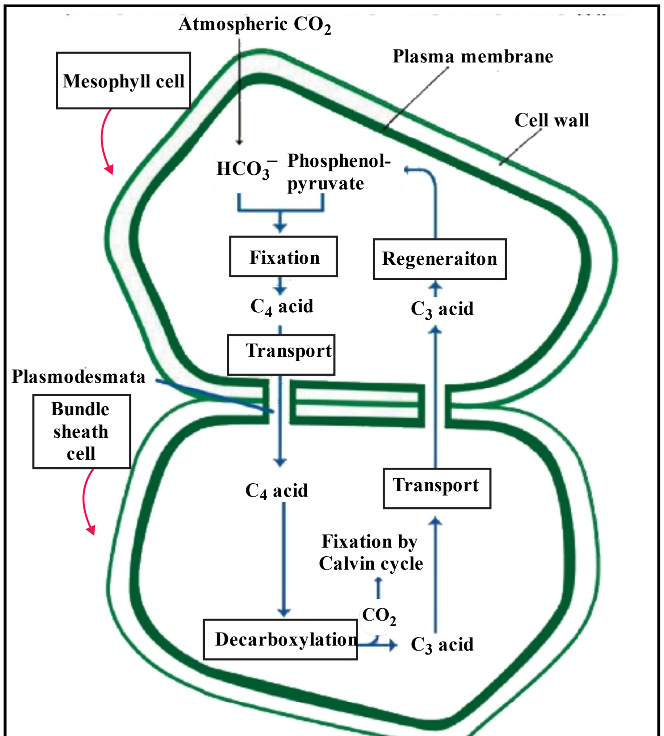


Figure : Diagrammatic representation of the Hatch and Slack Pathway

* Calvin cycle enzymes are present in stroma.
* Have, RUBP as primary acceptor and RUBISCO as enzyme for CO_2 fixation (C_3-cycle).
* The primary CO_2 acceptor is a 3-carbon molecule **phosphoenol pyruvate (PEP)** and is present in the mesophyll cells.
* The enzyme responsible for this fixation is **PEP carboxylase or PEPcase.**
* It is important to register that the mesophyll cells lack RuBisCO enzyme.
* The C_4 acid OAA is formed in the mesophyll cells.
* It then forms other 4-carbon compounds like malic acid or aspartic acid in the mesophyll cells itself, which are transported to the bundle sheath cells. In the bundle sheath cells these C_4 acids are broken down to release CO_2 and a 3-carbon molecule.
* The 3-carbon molecule is transported back to the mesophyll where it is converted to PEP again, thus, completing the cycle.
* The CO_2 released in the bundle sheath cells enters the C_3 or the Calvin pathway, a pathway common to all plants. The bundle sheath cells are rich in an enzyme Ribulose bisphosphate carboxylase-oxygenase (RuBisCO), but lack PEPcase.
* The basic pathway that results in the formation of the sugars, the Calvin pathway, is common to the C_3 and C_4 plants.

* **The differences between C_3 and C_4 Plants**

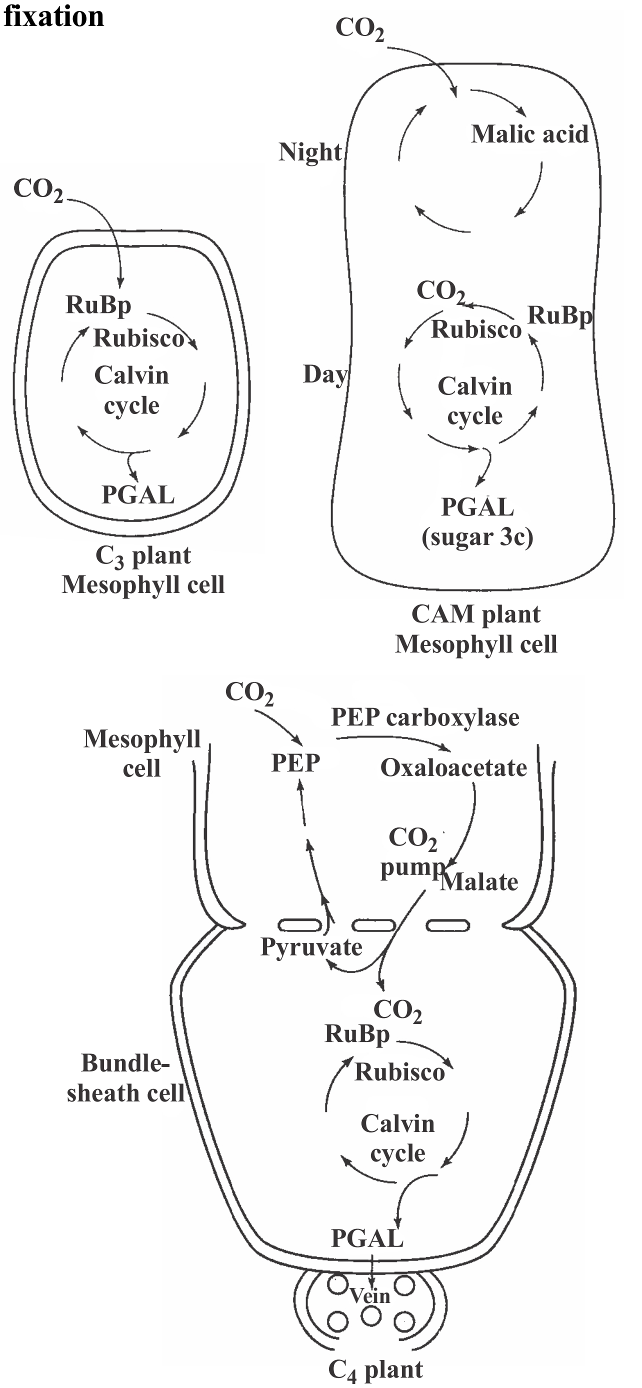
Characteristics	C_3 Plants	C_4 Plants
Cell type in which the Calvin cycle takes place.	Mesophyll	Bundle sheath
Cell type in which the initial carboxylation reaction occurs.	Mesophyll	Mesophyll
How many cell types does the leaf have that fix CO_2.	One	Two
Which is the primary CO_2 acceptor.	RuBP	PEP
Number of carbons in the primary CO_2 acceptor	5	3
Which is the primary CO_2 fixation product	PGA	OAA
No. of carbons in the primary CO_2 fixation product	3	4
Does the plant have RuBisCO?	Yes	Yes
Does the plant have PEP Case?	Yes	Yes
Which cells in the plant have Rubisco?	Mesophyll	Bundle sheath
CO_2 fixation rate under high light conditions	Medium	High
Whether photo-respiration is present at low light intensities	Negligible	Negligible
Whether photo-respiration is present at high light intensities	High	Negligible
Whether photo-respiration would be present at low CO_2 concentrations	High	Negligible
Whether photo-respiration would be present at high CO_2 concentrations	Negligible	Negligible
Temperature optimum	20-25°C	30-40°C
Examples	Wheat Rice	Maize Sugarcane Sorghum

CAM plants

* CAM plants are adapted to very dry climate like, pineapple, many cacti, etc.
* A CAM plant conserves water by opening its stomata and admitting CO_2 mainly at night. When CO_2 enters the leaves, it is incorporated into a four-carbon compound, as in C_4 plants.

* The four-carbon compound in a CAM plant banks CO_2 at night and release it to the Calvin cycle during the day. This keeps photosynthesis operating during the day, even though the leaf admits no more CO_2 because the stomata are closed.
* Note that in plants, C_3, C_4 and CAM types – it is the Calvin cycle that is ultimately responsible for sugar synthesis.

Comparison of C_3, C_4 and CAM plant carbon fixation



PHOTORESPIRATION

(C_2 Cycle or Glycolate Metabolism) :

* **Term given by Decker and Tio.**
* Photorespiration is a process which involves oxidation of organic compounds in plants by oxygen in the presence of light. Like ordinary respiration, this process also releases carbon from organic compounds in the form of carbon dioxide but does not produce ATP.
* Apparently it seems to be a **wasteful process**, but it must have some functions which are still unknown.
* The process occurs in C_3 plants only.
* There are **two oxygen consuming reactions** in this process. First oxidation occur in chloroplast and second oxidation occur in peroxisome.
* Photorespiration occurs usually when there is high concentration of oxygen. Under such circumstances RuBP carboxylase (or Rubisco), the enzyme that joins carbon dioxide to RuBP, functions as oxygenase. As a result, oxygen, instead of carbon dioxide, gets attached to the binding site of the enzyme (i.e., RuBP). **This reaction is competitive**.
* It is the relative concentration of O_2 and CO_2 that determines which of the two will bind to the enzyme. On oxidation, RuBP releases one molecule of C_3 compound.
* PGA (which enters C_3 cycle) and one molecule of a C_2 compound **phosphoglycolate**. The latter almost immediately changes into glycolate.
* The glycolate leaves the chloroplast and enters a membrane bound sac of enzymes called **peroxisome**. Here the glycolate is oxidised into glyoxylate which is aminated into **glycine**.
* Further condensation of glycine takes places inside the **mitochondria** where two molecules of glycine interact and give rise to a molecule of **serine** and carbon dioxide each. The CO_2 is then released from mitochondria.
* Serine regenerates PGA.
* With increase in temperature, high light intensity and oxygen concentration, affinity of Rubisco for CO_2 decreases and its affinity for oxygen increases.

Thus, a rise in temperature means more loss of photosynthetically fixed carbon by photorespiration.

* It reduces potential yield of plants growing in the tropics by 30-40%. Upto 1/4th of the photosynthetically fixed CO_2 may be lost by this pathway.
* 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 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.

FACTORS AFFECTING PHOTOSYNTHESIS

1. Light :

(a) Light Quality or wavelength : Maximum photosynthesis takes place in red light than in Blue light. But rate of photosynthesis is highest in white light. Minimum in green light.

(b) Light Intensity : There is a linear relationship between incident light and CO_2 fixation rates at low light intensities. At higher light intensities, gradually the rate does not show further increase as other factors become limiting (Figure).

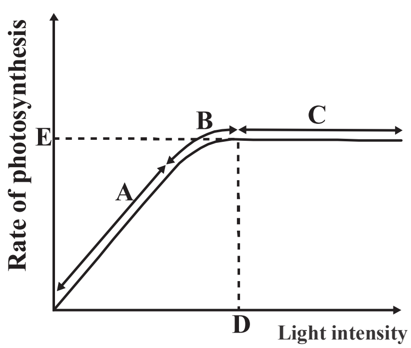


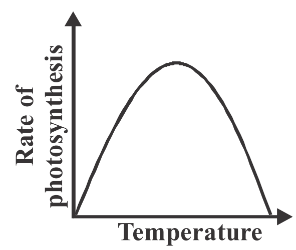
Figure : Graph of light intensity on the rate of photosynthesis

* Light saturation occurs at 10 per cent of the full sunlight. Hence, except for plants in shade or in dense forests, light is rarely a limiting factor in nature. Increase in incident light beyond a point causes the breakdown of chlorophyll and a decrease in photosynthesis.
* Plants which are adapted to grow in high intensity of light is called heliophytes & plants which are adapted to grow in shade is sciophytes.

(c) Duration of Light : On the basis of effect of light on plants may be LDP & SDP.

* Rate of photosynthesis is greater in intermittent light than continuous light - Warburg.

2. Temperature : Optimum temp. for photosynthesis is 20-35°C. At high temp. rate of photosynthesis decreases due to denaturation of enzymes. Conifers & lichens can perform photosynthesis at –20°C to – 35°C, while thermal algae Oscillatoria at 70-80°C. Generally different habitat plants show, different response to photosynthesis on a given temperature.



3. CO_2 : An increase in CO_2 conc. upto 1% rate of photosynthesis is increased. Higher CO_2 concentration is toxic to plant & also closes stomata.

. C_4-Plants can photosynthesize at low CO_2 conc. (upto 10 ppm). "CO_2 conc." at which CO_2 fixation in photosynthesis is equal to volume of CO_2 released in respiration is "CO_2 compensation point", when plant saturated with full light.

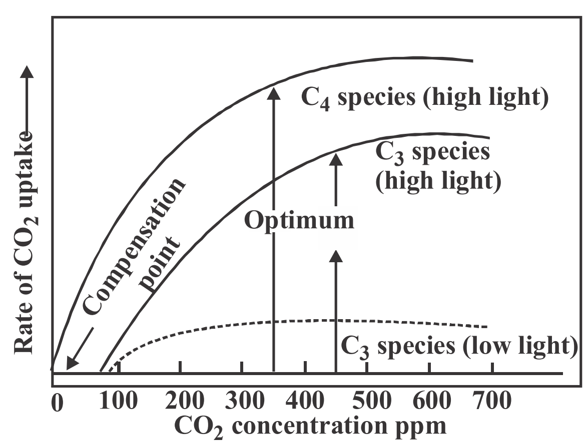


Figure : Photosynthetic response of C_3 and C_4 plants to CO_2 concentration.

CO_2 compensation point for C_4 plants is 8-10 ppm, while for C_3 plants it is 40-100 ppm.

4. **O_2 :** High O_2 conc. reduces photosynthesis due to photorespiration.

5. **Water :** Less availability of water reduces the rate of photosynthesis (stomata get closed)

6. **Chlorophyll :** The amount of CO_2 in grams absorbed by 1 gm. of chlorophyll in 1 hour is called as photosynthetic number or assimilatory number (Willstatter & Stoll).

7. **Product :** Rate of photosynthesis decreases, when sugar accumulates in mesophyll cells.

8. **Leaf :** Various leaf factors like leaf age and leaf orientation effect the rate of photosynthesis. In young & mature leaves photosynthesis is more than old (senescent) leaves.

9. **Inhibitors :** DCMU (Diuron/Dichlorophenyl Dimethyl Urea)CMU (Monuron), PAN,Atrazine, Simazime, Bromocil,; Isocil- inhibit the photosynthesis by blocking PS-II. They stop e^- flow between P-680 & PQ.

* In cyclic ETS diquat, paraquat (Viologen dyes) inhibit e- flow between P-700 & Fd.
* All these chemicals are used as herbicides, which mostly block ETS.

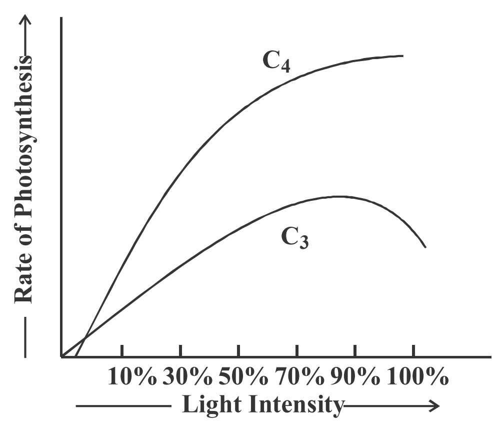
10. **Minerals :** Mg and Nitrogen are essential for structure of chlorophyll and enzymes. Thus reduction in N_2 and Mg supply to plants effects adversely the rate of photosynthesis.

* Rubisco alone accounts for more than half of total leaf nitrogen. Generally all essential element affect the rate of photosynthesis.
* **Concept of three cardinal points (Von Sachs) :** The effect of the various external factors on the rate of biological processes were centred around the attempts to establish minimum, optimum and maximum values known as cardinal points.
* **Law of minimum (Liebig) :** According to it, when a process is governed by a number of separate factors, then the rate of process is controlled by that factor present in minimum amount.
* **Law of limiting factors : (Blackman)** – It is the modification of Law of minimum by Liebig. "When a process is conditioned to its rapidity by a number of factors, then rate of process is limited by the pace of the slowest factor." (CO_2 light, chlorophyll, water, temp.)
* CO_2 becoming limiting in clear sky, but light limiting in cloudy days.
* Atmospheric CO_2 is not limiting factor for C4 plants & submerged hydrophytes.
* **Two categories of plants :**

  (a) Sciophytes : They grow under diffuse light, e.g., *Oxalis* etc.

  (b) Heliophytes : They grow in direct sunlight, e.g., *Dilbergia* etc.
* The optimum light intensity for sciophytes is 10% of full summer sunlight.
* The optimum light intensity for heliophytes is 50-70% of full summer sunlight.
* Optimum for C_4 plants is more than full summer sunlight. e.g., Maize, sugarcane. Optimum light intensity is also called saturation point.

Effect of light intensity on photosynthesis of C_4 and C_3 plant.



BACTERIAL PHOTOSYNTHESIS

* Certain bacteria are capable for photosynthesis. Eg : Chlorobium (Green Sulphur), Chromatium (Purple Sulphur), Rhodospirilium, Rhodopseudomonas (Purple non sulphur).
* Cyclic-photophosphorylation is an important method in bacterial photosynthesis.
* Absorption of Infra red spectrum takes place during bacterial photosynthesis thus no red drop.
* Pigment system of bacteria denoted by - B-890 or 870
* Evolution of O_2 is not related to bacterial photosynthesis, because water is not e^- donor (H_2S)

* Only one ATP is produced in each turn of cyclic photophosphorylation, in bacteria.
* Olson in 1970 gave a non cyclic scheme in bacterial photosynthesis.

$$6CO_2 + 12H_2S \xrightarrow[\text{Chromotophores}]{\text{IR Sperctrum}} C_6H_{12}O_6 + 6H_2O + 12S$$

* Bacteria has only one pigment system, PS I (PS II is absent).

CONCEPT REVIEW

* In plants, **photosynthesis** occurs in chloroplasts, which are located mainly within **mesophyll** cells inside the leaf.
* **Chloroplasts** are organelles enclosed by a double membrane; the inner membrane encloses the **stroma** in which membranous, saclike **thylakoids** are suspended. Each thylakoid encloses a **thylakoid lumen**. Thylakoids arranged in stacks are called **grana**.
* **Chlorophyll a, chlorophyll b, carotenoids**, and other photosynthetic pigments are components of the thylakoid membranes of chloroplasts.
* Photons excite biological molecules such as chlorophyll and other photosynthetic pigments, causing one or more electrons to become energized. These energized electrons may be accepted by electron acceptor compounds.
* The combined **absorption spectra** of chlorophylls a and b are similar to the **action spectrum** for photosynthesis.
* During photosynthesis, light energy is captured and converted to the chemical energy of carbohydrates; hydrogens from water are used to reduce carbon, and oxygen derived from water becomes oxidized, forming molecular oxygen.
* In the **light-dependent reactions**, electrons energized by light are used to generate **ATP** and **NADPH**; these compounds provide energy for the formation of carbohydrate during the **carbon fixation reactions**.
* **Photosystems I and II** are the two types of photosynthetic units involved in photosynthesis. Each photosystem includes chlorophyll molecules and accessory pigments organized with pigment binding proteins into **antenna complexes.**
* Only a special chlorophyll a in the **reaction center** of an antenna complex gives up its energized electrons to a nearby electron acceptor. **P700** is the reaction center for photosystem I; **P680** is the photosystem II reaction center.
* During the noncyclic light-dependent reactions, known as **noncyclic electron transport, ATP** and **NADPH** are formed. Electrons in photosystem I are energized by the absorption of light and passed through an electron transport chain to $NADP^+$, forming NADPH. Electrons given up by P700 in photosystem I are replaced by electrons from P680 in photosystem II. A series of redox reactions takes place as energized electrons are passed along the electron transport chain from photosystem II to photosystem I. Electrons given up by P680 in photosystem II are replaced by electrons made available by the photolysis of H_2O; oxygen is released in the process.
* During **cyclic electron transport**, electrons from photosystem I are eventually returned to photosystem I. ATP is produced by chemiosmosis, but no NADPH or oxygen is generated.
* **Photophosphorylation** is the synthesis of ATP coupled to the transport of electrons energized by photons of light. Some of the energy of the electrons is used to pump protons across the thylakoid membrane, providing the energy to generate ATP by **chemiosmosis.**
* The **carbon fixation reactions** proceed by way of the **Calvin cycle**, also known as the **C_3 pathway**.
* In the CO_2 uptake phase of the Calvin cycle, CO_2 is combined with ribulose bisphosphate (RuBP), a five-carbon sugar, by the enzyme ribulose bisphosphate carboxylase/oxygenase, commonly known as **rubisco**, forming the three-carbon molecule **phosphoglycerate (PGA).**

* In the carbon reduction phase of the Calvin cycle, the energy and reducing power of ATP and NADPH are used to convert PGA molecules to **glyceraldehyde-3-phosphate (G3P)**. For every 6 CO_2 molecules fixed, 12 molecules of G3P are produced, and 2 molecules of G3P leave the cycle to produce the equivalent of 1 molecule of glucose.
* In the RuBP regeneration phase of the Calvin cycle, the remaining G3P molecules are modified to regenerate RuBP.
* In **photorespiration**, C_3 plants consume oxygen and generate CO_2 by degrading Calvin cycle intermediates but do not produce ATP. Photorespiration is significant on bright, hot, dry days when plants close their stomata, conserving water but preventing the passage of CO_2 into the leaf.
* In the **C_4 pathway**, the enzyme **PEP carboxylase binds** CO_2 effectively, even when CO_2 is at a low concentration. C_4 reactions take place within mesophyll cells. The CO_2 is fixed in **oxaloacetate**, which is then converted to malate. The malate moves into a **bundle sheath cell**, and CO_2 is removed from it. The released CO_2 then enters the Calvin cycle.
* The **crassulacean acid metabolism (CAM)** pathway is similar to the C_4 pathway. PEP carboxylase fixes carbon at night in the mesophyll cells, and the Calvin cycle occurs during the day in the same cells.
* **Summary Reactions for Photosynthesis**

The light-dependent reactions (noncyclic electron transport):

$$12\ H_2O + 12\ NADP^+ + 18\ ADP + 18\ P_i \xrightarrow[\text{Chlorophyll}]{\text{Light}} 6\ O_2 + 12\ NADPH + 18ATP$$

The carbon fixation reactions (Calvin cycle):

$$12\ NADPH + 18\ ATP + 6\ CO_2 \rightarrow C_6H_{12}O_6 + 12\ NADP^+ + 18\ ADP + 18\ P_i + 6\ H_2O$$

By canceling out the common items on opposite sides of the arrows in these two coupled equations, we obtain the simplified overall equation for photosynthesis:

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

IMPORTANT POINTS

* Photophosphorylation means synthesis of ATP from ADP.
* In pigment system II, active chlorophyll is P_{680}.
* In case of C_4 pathway CO_2 combines with PEP.
* Red drop discovered by Emerson is due to disruption of photochemical activity of PS II.
* The C_4 plants are different from the C_3 plants with reference to the substances that accepts CO_2 in carbon assimilation.
* C_3 plants have high CO_2 compensation point.
* Bacterial photosynthesis contains PS I.
* PS II contains a nonchlorophyllus pigment in blue-green algae Phycocyanin.
* $NADP^+$s reduced to NADPH in noncyclic photopho-sphorylation.
* In C_4 plants, Calvin cycle operates in stroma of bundle sheath chloroplasts.
* Chlorophyll is found in grana of chloroplasts.
* Quantosomes occur in chloroplasts.
* Photo-oxidation or photolysis of water (in photosynthesis) occurs in association of PS II.
* Photorespiration is characteristic of C_3 plants.
* Noncyclic photophosphorylation is performed by both PSI and PS II.
* Carbon dioxide is fixed in dark reaction.
* PEP, the first CO_2 acceptor in C_4 cycle is is 3-C compound.
* Electrons lost by PS II are regained from H_2O.
* In CAM plants, organic acid content increases during night.
* Grana of chloroplast = Light reaction.
  Stoma of chloroplast = Dark reaction.
  Cytoplasm = Glycolysis
  Mitochondrial matrix = Krebs cycle.
* Onion is a C_4 plant.
* Coupling factor F occurs over thyllakoids.
* Malic acid is formed in C_4 plants in the cells of mesophyll.
* Light phase occurs in mesophyll cells.
* Chl a takes part in light reaction of photosynthesis.
* Sunflower does not show HSK pathway.

* CAM helps the plants in conserving water.
* Joseph Priestley - Showed that plants release O_2.
  Jan Ingenhousz - Showed that sunlight is essential for photosynthesis.
  Sachs - Plants produce glucose/starch.
  Van Niel - Hydrogen reduces CO_2 to carbohydrates.
* The first product of C_4 pathway is OAA.

* **Table : Noncyclic and Cyclic Electron Transport**

	Non-cyclic Electron Transport	**Cyclic Electron Transport**
Electron source	H_2O	None-electrons cycle through the system.
Oxygen released?	Yes (from H_2O)	No
Terminal electron acceptor	$NADP^+$	None-electrons cycle through the system
Form in which energy is temporarily captured	ATP (by chemiosmosis); NADPH	ATP (by chemiosmosis)
Photosystem(s) required	PS I (P700) and PS II (P680)	PS I (P700) only

* **Summary of Photosynthesis**

Reaction Series	**Summary of Process**	**Needed Materials**	**End Products**
Light-dependent reactions (take place in thylakoid membranes)	Energy from sunlight used to split water, manufacture ATP, and reduce $NADP^+$		
Photochemical reactions	Chlorophyll-activated; reaction center gives up photo excited electron to electron acceptor.	Light energy; pigments (chlorophyll)	Electrons
Electron transport	Electrons transported along chain of electron acceptors in thylakoid membranes; electrons reduce $NADP^+$; splitting of water provides some H^+ that accumulates inside thylakoid space.	Electrons, $NADP^+$, H_2O, electron acceptors.	NADPH, O_2
Chemiosmosis	H^+ permitted to diffuse across the thylakoid membrane down their gradient; they cross the membrane through special channels in ATP synthase complex; energy released is used to produce ATP.	Proton gradient, ADP + P_i	ATP
Carbon fixation reactions (take place in stroma)	Carbon fixation: Carbon dioxide used to make carbohydrate.	Ribulose bisphosphate, CO_2, ATP, NADPH, necessary enzymes.	Carbohydrates, ADP + P_i, $NADP^+$

QUESTION BANK

EXERCISE - 1 (LEVEL-1) [NCERT EXTRACT]

SECTION - 1 (VOCABULARY BUILDER)

Choose one correct response for each question.
For Q.1-Q.5

Match the column I with column II.

Q.1

Column I		Column II
(a) Thylakoids	(i)	Membrane sacs inside a chloroplast that has the photosynthetic pigments.
(b) Stroma	(ii)	A stack of membrane sacs inside a chloroplast.
(c) Granum	(iii)	Fluid inside the chloroplast
(d) Stomata	(iv)	Openings on the inner surface of the leaves to allow diffusion of gases in and out of the leaves

(A) (a) - i, (b)-iii, (c)-ii, (d)-iv
(B) (a) - i, (b)-ii, (c)-iii, (d)-iv
(C) (a) - ii, (b)-i, (c)-iii, (d)-iv
(D) (a) - iii, (b)-iv, (c)-i, (d)-ii

Q.2

Column I		Column II
(a) Peter Mitchell	(i)	Determined the chain arrangement of the electron carriers
(b) Andre Iagendorf & Earnest Uribe	(ii)	Demonstrated the use of different colors of light in photosynthesis
(c) Engelmann	(iii)	Explained the mechanism by which ATP synthase makes ATP.
(d) Robert Hill & Fay Bendall	(iv)	Elucidated the light-independent reactions of photosynthesis
(e) Melvin Calvin	(v)	Proved that H^+ gradient in chloroplast generates ATP

(A) (a) - iii, (b)-v, (c)-ii, (d)-i, (e)-iv
(B) (a) - i, (b)-ii, (c)-iii, (d)-iv, (e)-v
(C) (a) - ii, (b)-i, (c)-iii, (d)-v, (e)-iv
(D) (a) - i, (b)-iii, (c)-ii, (d)-iv, (e)-v

Q.3

Column I		Column II
(a) Photorespiration	(i)	Plants that fix CO_2 to make 3PGAL and glucose.
(b) Oxaloacetate	(ii)	Light stimulated use of oxygen and release of CO_2 in chloroplasts.
(c) C_3 plants	(iii)	Plants that make oxaloacetate at night and release CO_2 for Calvin cycle in the day.
(d) C_4 plants	(iv)	Plants that simultaneously make oxaloacetate and release CO_2 for Calvin cycle.
(e) CAM plants	(v)	Four carbon chemical produced by some plants as storage of CO_2.

(A) (a) - iii, (b)-v, (c)-ii, (d)-i, (e)-iv
(B) (a) - i, (b)-ii, (c)-iii, (d)-iv, (e)-v
(C) (a) - ii, (b)-v, (c)-i, (d)-iv, (e)-v
(D) (a) - i, (b)-iii, (c)-ii, (d)-iv, (e)-v

Q.4

Column I	Column II
(a) Photosynthesis	(i) Process by which certain organisms use light energy to convert simple organic chemicals into organic chemicals.
(b) Action spectrum	(ii) Plants and other photo-synthetic organisms that produce organic chemicals
(c) Primary producers	(iii) Organisms that live by eating plants and animals.
(d) Consumers	(iv) A curve that expresses the effectiveness of different color light on photo-synthesis.

(A) (a) - i, (b)-ii, (c)-iv, (d)-iii
(B) (a) - i, (b)-ii, (c)-iii, (d)-iv
(C) (a) - ii, (b)-i, (c)-iii, (d)-iv
(D) (a) - i, (b)-iv, (c)-ii, (d)-iii

Q.5

Column I	Column II
(a) C_4 plants	(i) Succulents
(b) Chlorophyll b	(ii) Accessory photosynthetic pigment
(c) PS II	(iii) Photo-oxidation of H_2O
(d) CAM	(iv) Kranz anatomy

(A) (a)-(iv), (b)-(ii), (c)-(iii), (d)-(i)
(B) (a)-(iii), (b)-(ii), (c)-(iv), (d)-(i)
(C) (a)-(i), (b)-(iii), (c)-(ii), (d)-(iv)
(D) (a)-(i), (b)-(ii), (c)-(iii), (d)-(iv)

SECTION - 2 (BASIC CONCEPTS BUILDER)

For Q.6 to Q.30 :

Choose one word for the given statement from the list.

ATP; light; chemical; ATP; NADPH; CO_2; glucose; ribulose bisphosphate ; Calvin; rubisco;thylakoids; two; stroma; five; carbon-fixation; one; three; 3-phosphoglycerate; six; light-dependent; 3-phosphoglyceraldehyde.

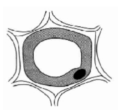
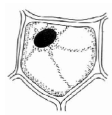
The main purpose of light-dependent reaction is to convert (6) ___ energy into (7) ___ energy, stored in (8) ___and (9) ___. These chemicals are used by the light-independent reaction to fix (10) _____ and form (11) ___. The cycle of reaction is also called (12) ___ cycle.

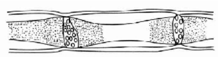
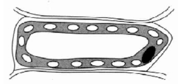
While light dependent reactions take place in (13) ___, light-independent reactions take place in the (14) ____ of chloroplast.

CO_2 combines with (15) ____ , a five-carbon sugar, to form a six-carbon chemical. This reaction is commonly referred to as the (16) ___ ___ step and uses an enzyme called (17) ___. This chemical splits into two three-carbon molecules of (18) ___ which then use energy of phosphate bond from three molecules of (19) ___ and high energy electrons from two molecules of (20) ___, both made by (21) ___ ___ reactions. As a result, two molecules of (22) ___ are formed. Through (23) ___ cycles of chemical reactions, (24) ___ molecules of this chemical are formed; out of which (25) ___ molecules are used to regenerate (26) ___ ___ while (27) ___ molecule is used to form (28) ___. However, the cycle must go around (29) ___ times before (30) ___ molecules of 3PGAL can be spared to make one glucose molecule.

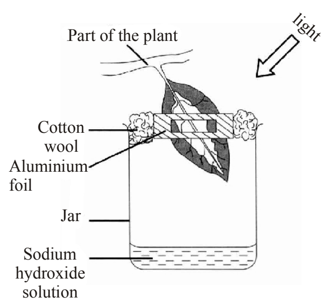
SECTION - 3 (ENHANCE DIAGRAM SKILLS)

Q.31 Which of the following plant cells is primarily involved in the synthesis of organic materials?

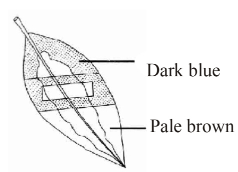
(A)  (B) 

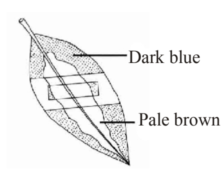
(C)  (D) 

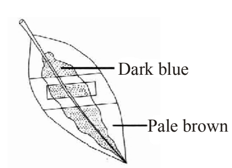
Q.32 A student conducted an experiment on photosynthesis as shown below. The plant was de-starched two days before the experiment. The shaded regions of the leaf were green. The middle part of the leaf was covered with an aluminium foil with a rectangular opening. The leaf was then exposed to the sun for several hours.

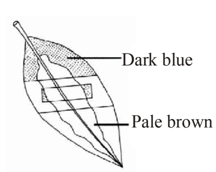


The leaf was then removed and treated with iodine. Which of the diagrams represents the result of the iodine test?

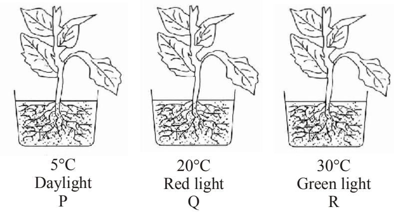
(A) 

(B) 

(C) 

(D) 

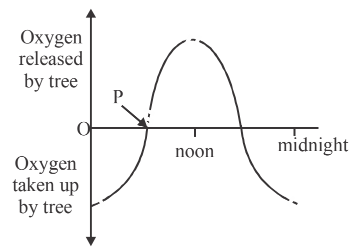
Q.33 The diagram below shows three green plants with identical leaf surface areas.



Assuming all other conditions were identical for all three plants, which of the plants would likely to photosynthesise the slowest and which the fastest?

(A) P is the slowest, R is the fastest.
(B) R is the slowest, Q is the fastest.
(C) P is the slowest, Q is the fastest.
(D) Q is the slowest, R is the fastest.

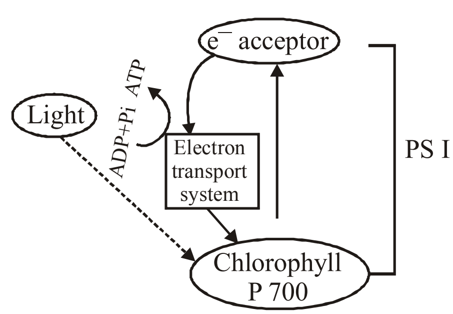
Q.34 The graph below shows oxygen released and taken up by a tree during a 24-hour period.



Which statement describes the situation at point P?

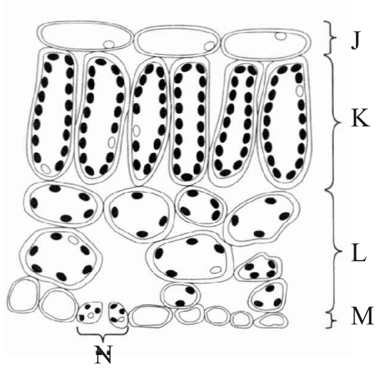
(A) Photosynthesis stops.
(B) Respiration begins.
(C) The rate of respiration is equal to the rate of photosynthesis.
(D) The rate of respiration is greater than the rate of photosynthesis.

Q.35 What does the given diagram represent with respect to the various photosynthetic processes?



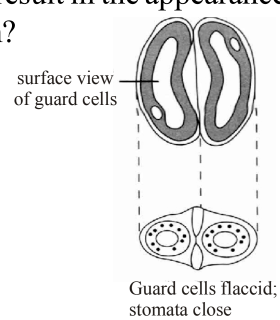
(A) C_2 cycle
(B) Cyclic photophosphorylation
(C) Non-cyclic photophosphorylation
(D) Z-scheme of phosphorylation

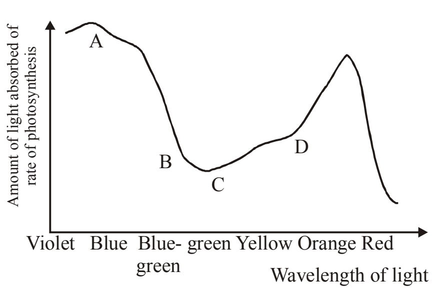
Q.36 The diagram shows the arrangement of cells inside a green leaf.



Which cells contain chloroplasts?
(A) J, K and L (B) J, L and M
(C) K, L and M (D) K, L and N

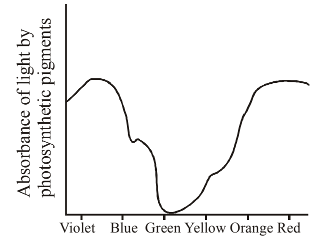
Q.37 In the graph below, a hibiscus plant has been exposed to a certain wavelength of light for 2 days. At which wavelength has the hibiscus plant been exposed to result in the appearance of its stomata as shown?





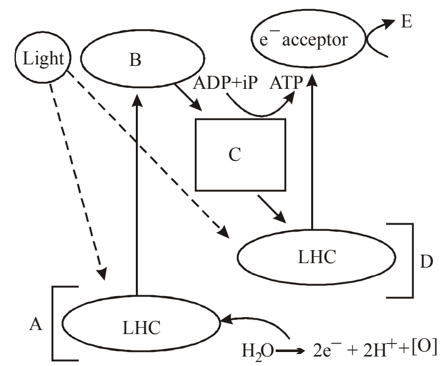
(A) A (B) B
(C) C (D) D

Q.38 The graph shows an absorption spectrum for an unknown pigment molecule. What color would this pigment appear?



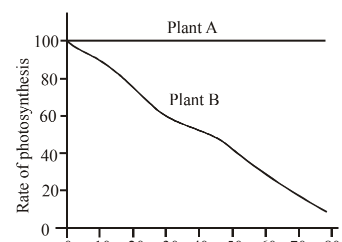
(A) red (B) yellow
(C) green (D) blue

Q.39 Identify A, B, C, D and E in the given flow chart showing Z-scheme of light reaction.



(A) A-P_{700}, B-H^+ acceptor, C-e^- acceptor, D-P_{680}, E-$NADP^+$
(B) A-Photo-system I, B-e^- acceptor, C-e^-transport system, D-Photo-system, E-NADPH
(C) A-Photo-system II, B-H^+ acceptor, C-e^- acceptor, D-P_{700}, E-NADPH
(D) A-Photo-system II, B-e^- acceptor, C-e^- transport system, D-Photo-system, E-NADPH

Q.40 This graph shows the rate of photosynthesis for two plants under experimental conditions.

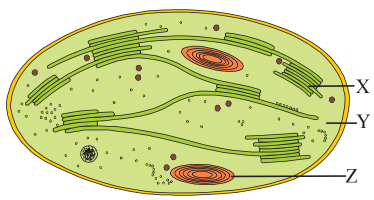


From this graph, what is the best conclusion about the mechanism of photosynthesis in the two plants?

(A) A is a C-3 plant, and B is a C-4 plant.
(B) A is a C-4 plant, and B is a C-3 plant.
(C) A is a CAM plant, and B is a C-4 plant.
(D) A and B are both CAM plants.

Direction for Q.41-Q.42

Refer the given diagrammatic representation of an electron micrograph of a section of chloroplast.



Q.41 Select the option that correctly identifies X, Y and Z.
(A) X-Stroma, Y- Grana, Z-Chloroplast DNA
(B) X-Stroma, Y-Grana, Z-Starch granule
(C) X-Grana, Y-Stroma, Z-Starch granule
(D) X-Grana, Y-Stroma, Z-Chloroplast DNA

Q.42 Selec the option which correctly depicts the functions of parts X, Y and Z.
(A) X-Dark reaction, Y-Light reaction, Z-Cytoplasmic inheritance
(B) X-Light reaction, Y-Carbohydrate synthesis, Z-Carbohydrate storage
(C) X-Light reaction, Y-Carbohydrate storage, Z-Carbohydrate synthesis
(D) X-Carbohydrate synthesis, Y-Carbohydratestorage, Z-Cytoplasmic inheritance

SECTION - 4 (ENHANCE PROBLEM SOLVING SKILLS)

Choose one correct response for each question.

PART - 1 : EARLY EXPERIMENTS

Q.43 An equation for photosynthesis is shown below.

$$X + \text{Water} \xrightarrow[\text{Y}]{\text{Sunlight}} \text{Carbohydrate} + Z$$

What are the identities of X, Y and Z?
(A) X-Carbon dioxide, Y-Chlorophyll, Z-Oxygen
(B) X-Carbon dioxide, Y-Chloroplast, Z-Oxygen
(C) X-Carbon dioxide, Y-Chloroplast, Z-Glucose
(D) X-Oxygen, Y-Chlorophyll, Z-CO_2

Q.44 Joseph Priestley observed that when mouse alone was placed in a closed bell jar with burning candle, it was suffocated and candle burning extinguished but when mouse was placed with a mint plant in the same bell jar, that mouse stayed alive and candle continued to burn. What he concluded from this experiment?
(A) Burning candle remove the air
(B) Mint plant restore the air
(C) Both (A) and (B)
(D) CO_2 is required for burning of candle

Q.45 In an experiment, a leaf was partially covered with black paper, and other one was exposed to light. On testing these leaves for starch, in the presence of sunlight, one may conclude that photosynthesis had occurred in –
(A) green part of leaves.
(B) black paper covered part of leaves.
(C) Both (A) and (B)
(D) None of the above

Q.46 Who demonstrated that green plants purify the foul air produced by breathing animals and burning candles?
(A) Priestley (B) Ingenhousz
(C) Sachs (D) Engelmann

Q.47 The first action spectrum of photosynthesis was described by Engelman was related to
(A) Algae (B) Mint plant
(C) Bacteria (D) Bryophytes

Q.48 Who provided the evidence for the production of glucose when plant grows?
(A) Julius von Sachs (B) Stephen Hales
(C) Lavoisier (D) von Helmont

Q.49 Who described the first action spectrum of photosynthesis?
(A) Sachs (B) Engelmann
(C) Arnold (D) von Helmont

Q.50 Who proposed that O_2 comes from water instead from CO_2 during photosynthesis?
(A) Van Neil (B) Engelmann
(C) Blackman (D) Warburg

PART - 2 : SITE OF PHOTOSYNTHESIS

Q.51 Chlorophyll
(A) contains magnesium in a porphyrin ring.
(B) dissolves in water.
(C) is green because it absorbs green portions of the light spectrum.
(D) is the only pigment found in most plants.

Q.52 Which of the following are present in photosystems?
(A) Carotenoids (B) Chlorophyll a
(C) Chlorophyll b (D) All of the above

Q.53 The part of a photosystem that absorbs light energy is
(A) antenna complexes
(B) reaction center
(C) terminal quinone electron acceptor
(D) pigment-binding protein

Q.54 Large number of chloroplast are present in which of the following cells?
(A) Parenchymatous cell
(B) Mesophyll cell
(C) Peroxisomal cell
(D) Cell wall

Q.55 Colour that we see in leaves is due to the presence of
I. chlorophyll-a II. chlorophyll-b
III. xanthophyll IV. carotenoid
(A) I and II (B) I, III and IV
(C) II, III and IV (D) I, II, III and IV

Q.56 What is the name given to the flattened membranous sacs which are embedded in the matrix of the chloroplast?
(A) Thylakoids (B) Granum
(C) Stroma (D) Mesophyll cells

Q.57 Study the following statements regarding chl a molecule.
(i) Molecular formula of chl a is $C_{55}H_{72}O_5N_4Mg$.
(ii) It is the primary photosynthetic pigment.
(iii) In pure state, it is red in colour and thus it absorbs more blue wavelength of light than the red wavelength.
(iv) It is soluble in water as well as petroleum ether.
Which of the above statements is/are not correct?
(A) (i) and (iii) (B) (iii) and (iv)
(C) (iii) only (D) (iv) only

Q.58 Functions of chloroplast of membrane system
(A) trapping of light energy
(B) synthesis of ATP
(C) synthesis of NADPH
(D) All of these

Q.59 Accessory pigments absorb light and transfer it to –
(A) chlorophyll-b (B) chlorophyll-a
(C) xanthophyll (D) carotenoids

Q.60 Where does the light reaction of photosynthesis occurs?
(A) Stroma (B) Grana
(C) ER (D) Cytoplasm

Q.61 Maximum number of chloroplast are found in
(A) root (B) stem
(C) leaves (D) short tip

Q.62 Accessory photosynthetic pigments in most green plants are
(A) chlorophyll a
(B) chlorophyll b
(C) carotenoids and xanthophylls
(D) both (B) and (C)

Q.63 What is the function performed by plant pigments?
(A) Absorb CO_2 (B) Absorb O_2
(C) Absorb H_2O (D) Absorb light

Q.64 By which plant pigment maximum absorption of radiation takes place in the blue and red regions of absorption spectrum?
(A) chlorophyll-a (B) chlorophyll-b
(C) xanthophyll (D) carotenoid

PART - 3 : LIGHT REACTION / PHOTOCHEMICAL PHASE

Q.65 Which of the following provides electrons to light dependent reactions?
(A) water (B) chlorophyll
(C) ATP (D) NADPH

Q.66 Which of the following gases is/are required by plants during the day?
(A) Oxygen only
(B) Carbon dioxide only
(C) Oxygen and carbon dioxide
(D) Nitrogen

Q.67 The ultimate gain of light reaction is :
(A) ATP & $NADPH_2$ (B) $NADPH_2$
(C) Only ATP (D) Only O_2

Q.68 Which during the light reaction of photosynthesis
(A) Chlorophyll is produced
(B) Water splits to form 2H^+ & O_2
(C) CO_2 is given off as a waste
(D) Sugar is formed from CO_2 and water

Q.69 Light Harvesting Complex (LHC) is
(A) one molecule of chlorophyll-a
(B) very few molecule of chlorophyll-a
(C) hundreds of pigment molecules bound to proteins.
(D) chlorophyll-a + chlorophyll-c + protein + DNA.

Q.70 Which of the following is produced during the light phase of photosynthesis?
(A) ATP (B) $NADPH_2$
(C) Both ATP & $NADPH_2$ (D) Carbohydrates

Q.71 Stroma lamellae membrane lacks
I. PS-II
II. NADP reductase
III. non-cyclic photophosporylation
Select the correct option.
(A) I and II (B) II and III
(C) III and I (D) I, II and III

Q.72 The water splitting complex is associated with
(A) PS-I (B) PS-II
(C) carotenoid (D) xanthophyll

Q.73 Photochemical phase does not include
(A) light absorption
(B) water splitting and O_2 release
(C) ATP and NADPH formation
(D) CO_2 fixation.

Q.74 The movement of electrons in ETC in light reaction is?
(A) up hill in terms of redox reaction
(B) down hill in terms of redox reaction
(C) Either (A) or (B)
(D) Both (A) and b)

Q.75 In cyclic photophosphorylation, the electron released by reaction centre (P_{700}) is ultimately accepted by
(A) ferredoxin (B) $NADP^+$
(C) reaction centre (P_{700}) (D) plastocyanin

Q.76 ATP and NADPH produced in light reaction by the movement of electrons in ETC are used immediately for –
(A) oxidation of carbohydrate
(B) synthesis of sugar
(C) reduction of carbon dioxide
(D) Both (B) and (C)

Q.77 The Z scheme of electron transport is
(A) cyclic photophosphorylation.
(B) non-cyclic photophosphorylation.
(C) Both (A) and (B).
(D) where only photosystem pigment-I is involved.

Q.78 Proton gradient is very important across the membrane because –
(A) Building up of proton gradient releases energy.
(B) Building up of proton gradient increases the pH towards lumen side of thylakoid membrane.
(C) Breakdown of proton gradient releases CO_2.
(D) Breakdown of proton gradient releases energy.

Q.79 _____ is the process of synthesis of ATP from ADP and Pi in the presence of light.
(A) Phosphorylation
(B) Photophosphorylation
(C) Photosystem
(D) Oxidative phosphorylation

Q.80 Cyclic photophosphorylation occurs in
(A) stroma lamellae
(B) appressed part of grana lamellae
(C) stroma cell wall
(D) grana cell wall

Q.81 Light reaction or photochemical phase includes
I. light absorption
II. water splitting
III. oxygen release
IV. ATP and NADP formation
Select the correct option.
(A) I, II and IV (B) I, II and III
(C) I, III and IV (D) I, II, III and IV

Q.82 PS-I has absorption peak at ___ and PS-II has absorption peak at. _____.
(A) 700 nm; 800 nm (B) 680 nm; 700 nm
(C) 700 nm; 680 nm (D) 800 nm; 700 nm

Q.83 Electrons are transferred by splitting of H_2O through ETC during light reaction and reduces
(A) NAD to NADH + H^+
(B) NADPH to H^+
(C) $NADP^+$ to NADPH + H^+
(D) NAD to NADPH + H^+

Q.84 NADP reductase enzyme is present on the
(A) lumen side of membrane
(B) lamellae side of membrane
(C) stroma side of membrane
(D) cell membrane of chloroplast membrane

Q.85 Cyclic phosphorylation occurs at which walvelength
(A) wavelength beyond 800 nm
(B) wavelength beyond 680 nm
(C) wavelength below 680 nm
(D) wavelength below 500 nm

Q.86 Formation of ATP in mitochondria is called
(A) mitochondria
(B) hydrolysis
(C) oxidative phosphorylation
(D) photophosphorylation

Q.87 What happen to the chloroplast pigment when they absorb light?
(A) They become reduced.
(B) They become excited.
(C) They loose potential energy.
(D) Calvin cycle is triggered.

Q.88 When two photosystem (I and II) work in a series, the phosphorylation is called
(A) cyclic (B) non-cyclic
(C) bicyclic (D) Both (A) and (B)

Q.89 Which hypothesis best explains the synthesis of ATP in chloroplast?
(A) Chemosynthetic hypothesis
(B) Chemiosmotic hypothesis
(C) Potential gradient hypothesis
(D) Redox gradient hypothesis

PART - 4 : DARK REACTION / BIOSYNTHETIC PHASE & CALVIN CYCLE

Q.90 The Calvin cycle begins when CO_2 reacts with
(A) phosphoenolpyruvate
(B) glyceraldehyde-3-phosphate
(C) ribulose bisphosphate
(D) oxaloacetate

Q.91 All of the following are part of Calvin cycle except
(A) chlorophyll. (B) rubisco
(C) RUBP (D) 3PGAL

Q.92 Most of 3PGAL formed during Calvin cycle are used to regenerate
(A) rubisco (B) glucose
(C) RUBP (D) CO_2

Q.93 In photosynthesis, hydrogen is transferred from the light reactions to dark reactions by –
(A) DPN (B) DNA
(C) ATP (D) NADP

Q.94 In dark reaction, first reaction is the
(A) Carboxylation (B) Decarboxylation
(C) Dehydrogenation (D) Deamination

Q.95 Biosynthetic phase is called as dark reaction because
(A) it depends on the light reaction.
(B) it does not depends on the light reaction.
(C) it does not depends on NADPH.
(D) it does not depends on ATP

Q.96 Rubisco stands for
(A) RuBP carboxylase oxygenase
(B) RuBP carbon dioxide oxygenase
(C) RuBP carbon dioxide oxidase
(D) RuBP carboxygenase oxidase

Q.97 In Calvin cycle, the first product identified was
(A) 3-phosphoglyceric acid
(B) 2-phosphoglyceric acid
(C) 1-phosphoglyceric acid
(D) 4-phosphoglyceric acid

Q.98 Which of the following statements about dark reactions is correct?
(A) They occur in darkness.
(B) They are not light dependent.
(C) They are dependent upon the products synthesized during light reactions.
(D) All of these.

Q.99 Biosynthetic phase of photosynthesis is the formation of
(A) lipid (B) fat
(C) protein (D) sugars

Q.100 In dark reaction, regeneration of RuBP needs
(A) 2 molecule of ATP (B) 1 molecule of ATP
(C) 3 molecule of ATP (D) 4 molecule of ATP

Q.101 Calvin cycle can be described under three stages. These stages are
I. carboxylation II. ligation
III. reduction IV. regeneration
Select the correct option.
(A) II, III and IV (B) I, III and IV
(C) I, II and IV (D) I, II and III

Q.102 Every CO_2 molecule entering the Calvin cycle needs
(A) 2 molecule of NADPH and 3 molecule of ATP for its fixation
(B) 2 molecule of NADPH and 2 molecule of ATP for its fixation.
(C) variable amount of ATP
(D) only NADPH.

Q.103 If the light becomes unavailable during photosynthesis then –
(A) immediately biosynthetic process stops.
(B) biosynthetic phase does not stops.
(C) biosynthetic phase stopes forever.
(D) biosynthetic phase continues for some time and then stops.

Q.104 Fixation of six molecules of CO_2 needs
(A) 5 turns of Calvin cycle
(B) 6 turns of Calvin cycle
(C) 3 turns of Calvin cycle
(D) 2 turns of Calvin cycle

PART - 5 : THE C_4 PATHWAY

Q.105 Carbon dioxide acceptor in C_4 plants is –
(A) Phosphoenol pyruvic acid (PEP)
(B) Ribulose-1, 5-diphosphate
(C) NADP
(D) Ribulose-5-phosphate

Q.106 Which of the following is C_4 plants
(A) Maize (B) Atriplex
(C) Sugarcane (D) All of the above

Q.107 C_4 plants are adapted to –
(A) Hot and dry climate
(B) Temperate climate
(C) Cold and dry climate
(D) Hot and Humid climate

Q.108 In case of C_4 pathway, in the first step is
(A) CO_2 combines with RuDP
(B) CO_2 combines with PGA
(C) CO_2 combines with PEP
(D) CO_2 combines with RMP

Q.109 The enzyme which catalyzes the photosynthetic C_4 cycle
(A) RUDP carboxylase (B) PEP carboxylase
(C) Carbonic anhydrase (D) None of these

Q.110 The family in which many plants are C_4 type
(A) Malvaceae (B) Solanaceae
(C) Crucifereae (D) Graminae

Q.111 I. They have special leaf anatomy.
II. They tolerate high temperature.
III. Lack photo respiration.
IV. Greater productivity of biomass.
These are the probable characters of
(A) C_2-plant (B) C_3-plant
(C) C_4-plant (D) Any plant

Q.112 Which of the following statement is false in case of C_4-plant ?
(A) CO_2 acceptor is RuBisCo in mesophyll cell
(B) Carboxylation occurs in mesophyll cells
(C) Leaves have two cell types
(D) Mesophyll cells lack Rubisco

Q.113 Rubisco enzyme is absent in
(A) mesophyll cell (B) bundle sheath cell
(C) C_3-plants (D) C_4-plants

Q.114 In an experiment in which photosynthesis is performed during the day, you provide a plant with radioactive carbon dioxide ($^{14}CO_2$) as a metabolic tracer. The ^{14}C is incorporated first into oxaloacetic acid. The plant is best characterized as a –
(A) C_4 plant (B) C_3 plant
(C) CAM plant (D) insectivorous plant

Q.115 In C_4 -pathway, the first product identified was
(A) 3-PGA (B) OAA
(C) 2-PGA (D) 1-3 DPGA

Q.116 In C_4 -plants, the carbon dioxide fixation occurs in –
(A) guard cells (B) spongy cells
(C) palisade cells (D) bundle sheath cells

Q.117 Kranz anatomy is the characteristics of
(A) C_5-plants (B) C_3-plants
(C) C_2-plants (D) C_4-plants

Q.118 Generally, plants adapted to dry tropical conditions have
(A) C_2 pathway (B) C_3 pathway
(C) C_5 pathway (D) C_4 pathway

Q.119 Bundle sheath cells are rich in which enzyme
(A) PEP carboxylase
(B) malate dehydrogenase
(C) phosphofructokinase
(D) RuBisCo

Q.120 Primary acceptor of CO_2 in C_4-cycle is
(A) PGA (B) PEP
(C) RuBP (D) OAA

PART - 6 : PHOTORESPIRATION

Q.121 Photorespiration in C_3 plants starts from –
(A) Phosphoglycerate (B) Glycerate
(C) Glycine (D) Phosphoglycolate

Q.122 In C_3 plant, when O_2 concentration is more, the O_2 binds to Rubisco and RuBP gets changed to
(A) 2 moleculs of PGA
(B) 2 molecules of phosphoglycerate
(C) 2 molecules of phosphoglycolate
(D) one molecule each of phosphoglycerate and phosphoglycolate

Q.123 Find out the reason that creates an important difference between C_3 and C_4 -plant.
(A) photorespiration (B) calvin cycle
(C) glycolysis (D) pressure of cuticle

Q.124 In the photorespiration pathway, there is neither synthesis of sugar nor of _____. Rather it results in release of _____ with utilisation of _____.
(A) Protein, O_2, ATP (B) Protein, CO_2, ATP
(C) ATP, CO_2, ATP (D) ATP, O_2, ATP

Q.125 Rubisco has the active site that binds to
(A) CO_2 (B) O_2
(C) Either (A) or (B) (D) NO_2

Q.126 In photorespiration, (which is light induced cyclic oxidation of photosynthetic intermediates with the help of oxygen) the substrate is
(A) glycolate (B) glucose
(C) pyruvic acid (D) acetyl Co·A

Q.127 How many ATP and $NADPH_2$ are respectively produced in the process of photorespiration?
(A) 2 and 4 (B) 1 and 2
(C) 4 and 6 (D) 0 and 0

PART - 7 : FACTORS AFFECTING PHOTOSYNTHESIS

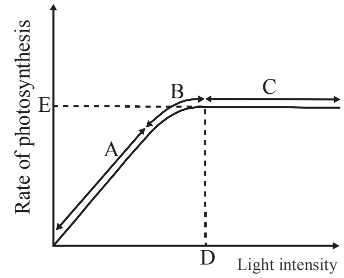
Q.128 The rate of photosynthesis does not depend upon
(A) Light duration (B) Light intensity
(C) Light quality(colour) (D) Temperature

Q.129 Optimum temperature of photosynthesis is
(A) 10 - 15°C (B) 20 - 25°C
(C) 20 - 35°C (D) 35 - 50°C

Q.130 Which one of the following have high CO_2 compensation point –
(A) C_2 plants (B) C_3 plants
(C) C_4 plants (D) Alpine herbs

Q.131 Law of limiting factor in relation to photosynthesis is proposed by
(A) Blackman (B) Wiseman
(C) Calvin (D) Emerson

Q.132 Study the given graph showing the effect of light intensity on the rate of photosynthesis. Which of the following statements regarding this is correct?



(A) Light is a limiting factor in the region A.
(B) Region C represents that rate of photosynthesis is not increased further by increasing light intensity because some other factor became limiting.
(C) Point D represents the intensity of light at which some other factor became limiting.
(D) All of these

Q.133 If a chemical process is affected by more than one factors then its rate will be determined by
(A) two closely related factors.
(B) only one factor, which is close to its minimal value.
(C) only one factor, which is close to its maximum value.
(D) only one factor, which is close to its appropriate value.

Q.134 ____ plants have the higher temperature optimum than the plants adapted to ____ climate.
(A) Desert; Tropical (B) Temperate; Tropical
(C) Tropical; Temperate (D) Desert; Temperate

Q.135 Maximum photosynthesis occurs in
(A) red light (B) blue light
(C) green light (D) violet light

Q.136 Which of the following is not an external factor influencing photosythesis?
(A) CO_2 concentration
(B) O_2 concentration
(C) Availability of water
(D) Chlorophyll concentration

Q.137 Water stress causes the stomata to ____ hence reducing the ____ availability.
(A) open; H_2O (B) close; H_2O
(C) close; CO_2 (D) open; CO_2

EXERCISE - 2 (LEVEL-2)

Choose one correct response for each question.

Q.1 Which of the following would reduce the rate of photosynthesis?
(A) A decrease in atmospheric carbon dioxide level.
(B) An increase in temperature
(C) An increase in average rainfall
(D) An increase in sunlight level

Q.2 In which of the following ways is the product of photosynthesis used by plants?
(a) As a source of energy
(b) Being converted to storage material
(c) To build up cell wall
(A) (a) and (b) only (B) (a) and (c) only
(C) (b) and (c) only (D) (a), (b) and (c)

Q.3 Which of the following acts as the reaction center molecule?
(A) Carotenoids (B) Chlorophyll a
(C) Chlorophyll b (D) All of the above

Q.4 The inputs for ___ are CO_2, NADPH, and ATP.
(A) cyclic electron transport
(B) the carbon fixation reactions
(C) noncyclic electron transport
(D) photosystems I and II

Q.5 Which of the following statements is incorrect regarding the Calvin cycle of C_3 plants?
(A) First stable product of Calvin cycle in C_3 plants is 3-Phosphoglyceric acid.
(B) Sunflower is an example of C_3 plants.
(C) Calvin cycle occurs in bundle sheath cells of C_3 plants.
(D) Enzyme PEPcase is absent in C_3 plants.

Q.6 In photolysis, some of the energy captured by chlorophyll is used to split
(A) CO_2 (B) ATP
(C) NADPH (D) H_2O

Q.7 The relative effectiveness of different wavelengths of light in photosynthesis is demonstrated by –
(A) an action spectrum
(B) photolysis
(C) carbon fixation reactions
(D) photoheterotrophs

Q.8 Which of the following produces ATP and NADPH?
(A) Calvin cycle
(B) cyclic electron flow
(C) noncyclic electron flow
(D) None of these

Q.9 In _____, there is a one-way flow of electrons to $NADP^+$, forming NADPH.
(A) crassulacean acid metabolism
(B) the Calvin cycle
(C) photorespiration
(D) noncyclic electron transport

Q.10 The mechanism by which electron transport is coupled to ATP production by means of a proton gradient is called
(A) chemiosmosis
(B) crassulacean acid metabolism
(C) fluorescence
(D) the C_3 pathway

Q.11 Which of the statements about photosynthesis is INCORRECT?
(A) Energy is released during photosynthesis.
(B) Photosynthesis occurs only in the presence of light.
(C) Glucose is a product formed during photosynthesis.
(D) Starch is a product formed during photosynthesis.

Q.12 Chloroplasts in prokaryotic cells –
(A) possess a CF_0-CF_1 complex
(B) have double membranes
(C) do not exist
(D) contain chlorophyll

Q.13 Which one of the following is NOT required for photosynthesis to occur?
(A) CO_2 (B) O_2
(C) ATP (C) NADP

Q.14 Which one is NOT correct about where the Calvin cycle occurs?
(A) in the spongy mesophyll in C-3 plants
(B) in the mesophyll in C-4 plants
(C) in the palisade layer in C-3 plants
(D) in the bundle sheath in C-4 plants

Q.15 In __, electrons that have been energized by light contribute their energy to add phosphate to ADP, producing ATP.
(A) crassulacean acid metabolism
(B) the Calvin cycle
(C) photorespiration
(D) photophosphorylation

Q.16 How many molecules of 3PGAL are made during each Calvin cycle?
(A) 1 (B) 2
(C) 3 (D) 6

Q.17 Which of the following is true about green leaves?
(A) They absorb green light only.
(B) They absorb mostly green light.
(C) They do not absorb green light.
(D) They absorb infrared light only.

Q.18 The process of photo-phosphorylation take place in –
(A) Chloroplast (B) Ribosomes
(C) Mitochondria (D) Cell-wall

Q.19 Photophosphorylation means synthesis of –
(A) ATP from ADP (B) NADP
(C) ADP from ATP (D) PGA

Q.20 What will be left if chlorophyll is burnt –
(A) Magnesium (B) Manganese
(C) Iron (D) Sulphur

Q.21 Solar energy is converted into ATP in –
(A) Mitochondria (B) Chloroplast
(C) Ribosome (D) Peroxisome

Q.22 The first step in photosynthesis is –
(A) Joining of three carbon atoms to from glucose
(B) Formation of ATP
(C) Ionization of water
(D) Excitement of an electron of chlorophyll by a photon of light.

Q.23 Which one of the following concerns with photophosphorylation –
(A) $ADP + AMP \xrightarrow{\text{Light energy}} ATP$
(B) $ADP + \text{Inorganic } PO_4 \xrightarrow{\text{Light energy}} ATP$
(C) $AMP + \text{Inorganic } PO_4 \xrightarrow{\text{Light energy}} ATP$
(D) None of these

Q.24 The function of ATP in photosynthesis is the transfer of energy from the –
(A) Dark reaction to the light reaction
(B) Light reaction to the dark reaction
(C) Chloroplasts to mitochondria
(D) Mitochondria to chloroplasts

Q.25 During photochemical reaction of photosynthesis
(A) liberation of O_2 takes place.
(B) Formation of ATP and $NADPH_2$ take place.
(C) Liberation of O_2, formation of ATP, $NADPH_2$ takes place.
(D) Assimilation of CO_2 takes place

Q.26 What is the first stable intermediate product of photosynthesis :
(A) Glucose (B) Formaldehyde
(C) phosphoglyceric acid (D) PGAL

Q.27 Which pigment is water soluble –
(A) Chlorophyll (B) Carotene
(C) Anthocyanin (D) Xanthophyll

Q.28 Number of ATP molecules required for regeneration phase of' RuBP during synthesis of 1 glucose molecule
(A) 6 (B) 12
(C) 18 (D) 30

Q.29 Solarisation is a process in which –
(A) Sugar are formed with the help of solar energy.
(B) Chlorophyll is formed.
(C) Destruction of chlorophyll and ultimate death of protoplasmic components.
(D) Mobilization of light energy.

Q.30 During day light hours, the rate of photosynthesis is higher than that of respiration and the ratio of oxygen produced to that of consumed is –
(A) 10 : 1 (B) 5 : 1
(C) 1 : 1 (D) 50 : 1

Q.31 Generally CO_2 is not limiting for hydrophytes –
(A) Mesophytes plants fix H_2S in their photosynthesis.
(B) These plants also uses CO_2 from water in the form of HCO_3^-.
(C) Glucose is not required for their respiration.
(D) All the above

Q.32 Which photosystem is involved in cyclic photophosphorylation?
(A) PS-II
(B) PS-I
(C) Xanthophyll and PS-II
(D) Xanthophyll and PS-I

Q.33 pH of thylakoid lumen during photosynthesis is
(A) basic
(B) neutral
(C) acidic
(D) depends on H^+ concentration

Q.34 Synthesis of complex organic substances from simple inorganic raw materials in the presence of sunlight and chlorophyll is called as ____ , which is a _____ process.
(A) photosynthesis, anabolic
(B) photosynthesis, catabolic
(C) respiration, anabolic
(D) respiration, catabolic

Q.35 Within the chloroplast, there is the membranous system consisting of
I. grana. II. stroma lamellae.
III. fluid stroma.
Choose the correct option.
(A) I and II (B) II and III
(C) I and III (D) I, II and III

Q.36 During the light reaction, the water splits into
(A) H^+, O_2 electrons
(B) H_2, O_2 electrons
(C) $2H^+$, $\frac{1}{2}O_2$,2 electrons
(D) $\frac{1}{2}H_2$, $\frac{1}{2}O_2$ electrons

Q.37 The electrons in the reaction centre of PS-I are
(A) excited simultaneously with PS-II
(B) excited simultaneously with P_{680}
(C) excited simultaneously with P_{700}
(D) Either (A) or (B)

Q.38 Main biosynthetic pathway for CO_2 fixation in C_4-plant is
(A) C_4 pathway (B) C_3 pathway
(C) C_2 pathway (D) Both (A) and (B)

Q.39 Water is –
(A) produced in dark reaction
(B) a reactant in light reaction
(C) Both (A) and (B)
(D) involve nowhere in photosynthesis

Q.40 Plants in which the first product of CO_2 fixation is C_3 acid, i.e.,. the _____ pathway, and those in which the first product was C_4 acid (OAA), i.e., the ____ pathway.
(A) C_2; C_3 (B) C_3; C_4
(C) C_4; C_2 (D) C_2; C_3

Q.41 Which one is involved in Z-scheme of photosynthesis?
(A) PS I (B) PS II
(C) e^- carriers (D) All of these

Q.42 Pigments can be separated from leaf by
(A) ELISA test (B) RIA test
(C) centrifugation (D) paper chromatography

Q.43 Protons produced by the splitting of water in light reaction of photosynthesis accumulates within the
(A) lumen of thylakoids
(B) intermembrane of chloroplast
(C) stroma of chloroplast
(D) outside the lumen of thylakoids

Q.44 Factors affecting photosynthesis are
I. number and size of leaves.
II. age and orientation of leaves.
III. amount of chlorophyll.
IV. amount of O_2 and CO_2
Select the correct option.
(A) I, II and IV (B) II, IV and V
(C) IV, V and I (D) I, II, III and IV

Q.45 Photosystem I (PS-I) and Photosystem-II (PS-II) are named –
(A) in the sequence they work in light reaction
(B) according to their molecular weight
(C) in the sequence of their discovery
(D) in the sequence of their constituents

Q.46 Water stress makes plant leaves ____ thus, ___ the surface area of leaves and their metabolic activity as well.
(A) wilt, increases (B) wilt, decreases
(C) fall, decreases (D) fall, increases

Q.47 During the dark reaction, the acceptor of CO_2 is
(A) $NADPH_2$ (B) RuBP
(C) H_2O (D) CO_2

Q.48 Flow of electrons in non-cyclic photo phosphorylation is
(A) unidirectional (from PS-I to PS-II)
(B) amphidirectional
(C) bidirectional
(D) unidirectional (from PS-II to PS-I)

Q.49 Products of light reaction are ATP, ___ and O_2, of these, ___ diffuses out of the chloroplast, while ATP and NADPH are used to derive the process leading to the synthesis of food more accurately, ___.
(A) NADP; O_2; lipid
(B) $NADPH_2$; O_2; amino
(C) NAD^+; O_2; sugars
(D) $NADPH + H^+$; O_2; sugars

Q.50 C_4-plant minimises the photorespiration because C_4-plants
(A) use PEPcase to initiate CO_2 fixation
(B) do not carry out the Calvin cycle in low CO_2 level
(C) exclude Calvin cycle
(D) show photorespiration

Q.51 During non-cyclic photophosphorylation, electrons are continuously lost from the reaction centre of PS II. Which source is used to replace these electrons?
(A) Sunlight (B) O_2
(C) H_2O (D) CO_2

Q.52 CO_2 released in bundle sheath is used in the
(A) C_4-cycle (B) C_3-cycle
(C) respiration (D) sugar break down

Q.53 The internal factors that affects photosynthesis of plant depends on the
(A) morphological predisposition
(B) genetic predisposition
(C) temperature
(D) environmental predisposition

Q.54 PS-I in cyclic photophosphorylation is involved in the formation of ___ by ___ movement of electrons.
(A) ATP; down hill redox potential
(B) ADP; up hill redox potential
(C) $NADH + H^+$; down hill energy
(D) $NADPH + H^+$; down hill energy

Q.55 Assuming a thylakoid is somehow punctured so that the interior of the thylakoid is no longer separated from the stroma. This damage will have the most direct effect on which of the following processes?
(A) Splitting of water.
(B) Absorption of light energy by chlorophyll.
(C) Flow of electrons from photosystem II to photosystem I.
(D) Synthesis of ATP

Q.56 Biosynthetic phase of photosynthesis is dependent on
I. NADPH II. NADH
III. ATP IV. $NAD^+ + H^+$
Select the correct option.
(A) I and III (B) IV and I
(C) I and IV (D) IV and II

Q.57 $PEP + CO_2 + H_2O \xrightarrow{X}$ Oxaloacetic acid $+ H_3PO_4$. Identify X
(A) ligase (B) oxidoreductase
(C) PEP carboxylase (D) lyase

Q.58 $RuBP + O_2 \xrightarrow{X}$ PGA + Phosphoglycolate. Identify X in the given equation and choose the correct option.
(A) RuBP carboxylase (B) RuBP oxygenase
(C) RuBisCo (D) PEP-carboxylase

Q.59 Tropical plants have a ___ temperature optimum than the plants adapted to temperate climates.
(A) lower (B) equal
(C) higher (D) none of these

Q.60 ATP synthesis is linked to
(A) development of pressure gradient across membrane.
(B) development of osmotic gradient across membrane.
(C) development of proton gradient across membrane.
(D) development of electron gradient across membrane.

Q.61 What happens to C_4 acid in the bundle sheath cells?
(A) Aspartic acid is deaminated
(B) Malic acid decarboxylated
(C) Both (A) or (B)
(D) None of the above

Q.62 $RuBP + CO_2 \xrightarrow{Rubisco} X.$ in the given
Identify X in the given
(A) 2 × 2 PGA (B) 2 × 3 PGA
(C) 2 × 4 PGA (D) 2 × 1 PGA

Q.63 Optimum temperature conditions for photosynthesis in C_3 & C_4 plants are respectively
(A) 10°C-25°C and 30°C-45°C
(B) 30°C-45°C and 10°C-25°C
(C) 0°C-10°C and 10°C-30°C
(D) 25°C-30°C and 40°C-50°C

Q.64 Chemiosmosis requires
I. a membrane II. a proton pump
III. a proton gradient
Select the correct option
(A) II and III (B) I and III
(C) I and II (D) I, II and III

Q.65 ATP synthesised by cells in
I. chloroplast II. mitochondria III. Golgi body
Select the correct option.
(A) I and III (B) I and II
(C) II and III (D) I, II and III

Q.66 Carboxylation (C_3-cycle) is catalysed by
(A) Carboxylase (B) RuBP carboxylase
(C) RuBP oxygenase (D) Both (B) and (C)

Q.67 Which of the following statements are correct?
I. Light reaction occurs in stroma.
II. Light reaction occurs in grana.
III. Dark reaction occurs in stroma.
IV. Dark reaction occurs in grana.
Choose the correct option.
(A) I and II (B) II and IV
(C) III and IV (D) II and III

Q.68 Kranz anatomy is not exhibited by which of the following plants?
(A) Maize (B) Sorghum
(C) Sugarcane (D) Sunflower

Q.69 In photosystem, antennae includes all pigments except
(A) chlorophyll-a (B) chlorophyll-a
(C) carotenoids (D) xanthophyll

Q.70 In dark reaction, reduction involves the utilisation of ____ molecule of ATP for phosphorylation and ____ molecule of NADPH for the reduction per CO_2 molecule.
(A) 2; 3 (B) 4; 2
(C) 2; 4 (D) 2; 2

EXERCISE - 3 (LEVEL-3)

Choose one correct response for each question.

Q.1 Electrons which gets excited in PS-I must be replaced. These replacement ultimately come from
(A) ATP (B) H_2O
(C) PS-II (D) NADPH

Q.2 When temperature is increased from minimum to optimum, rate of photosynthesis doubles for every _____ rise in temperature.
(A) 1°C (B) 10°C
(C) 20°C (D) 30°C

Q.3 Along with the electrons that come from the acceptor of electrons of ____, protons are necessary for the reduction of $NADP^+$ to ____. These protons are also removed from the ____.
(A) PS·II, NADPH + H^+, stroma
(B) PS·I, NADPH + H^+, stroma
(C) PS·I, NADPH + H^+, lumen
(D) PS·II, NADPH + H^+, lumen

Q.4 Red colour of tomatoes, carrots and chillies is due to the presence of a type of carotene pigment called as
(A) lutein (B) lycopene
(C) fucoxanthin (D) phycoerythrin

Q.5 **Statement I :** C_3-plant respond to lower CO_2 concentration by showing increased rate of photosynthesis.
Statement II : C_4 -plant respond to higher CO_2 concentration by showing decreased rate.
(A) Both I and II statements are correct
(B) Statement I is correct. II is incorrect
(C) Statement II is correct, I is incorrect
(D) Both I and II statements are incorrect

Q.6 If green plant cells are incubated with O^{18}-labelled CO_2, which of the following molecules will become radioactive when the cells are exposed to light?
(A) ATP (B) Water
(C) Sugar (D) O_2

Q.7 I. In photosynthesis, the proton accumulation is towards the inside of membrane of thylakoid.
II. In respiration, proton accumulation occurs in the inter membrane space of the mitochondria.
Select the correct option.
(A) statement I is incorrect II is correct.
(B) statement II is incorrect I is correct.
(C) Both statement I and statement II incorrect
(D) Both statement I & statement II are correct

Q.8 The herbicide DCMU kills the weeds because it inhibits
(A) respiration (B) CO_2 fixation
(C) cell division (D) NO_3^{2-} uptake.

Q.9 In dark cycle, one molecule of glucose formation needs
(A) 12 ATP and 12 NADPH
(B) 14 ATP and 12 NADPH
(C) 16 ATP and 12 NADPH
(D) 18 ATP and 12 NADPH

Q.10 Warburg effect refers to
(A) decreased photosynthetic rate at very high O_2 concentration.
(B) increased photosynthetic rate at very high O_2 concentration.
(C) decreased photosynthetic rate at very low O_2 concentration.
(D) increased photosynthetic rate at very low O_2 concentration.

Q.11 I. In C_3-plant, Calvin pathway takes place in mesophyll cell.
II. In C_4 -plant, Calvin pathway takes place in the mesophyll cell.
Which of the following statement true?
Choose the correct option.
(A) Statement I is incorrect, II is correct.
(B) Statement II is incorrect, I is correct.
(C) Both incorrect.
(D) Both correct.

Q.12 Select the incorrect statement as far as kranz anatomy is concerned.
(A) Undifferentiated mesophyll occurs in concentric layers around vascular bundles.
(B) Centrifugal chloroplasts are present in bundle sheath cells.
(C) Large sized bundle sheath cells are arranged in a wreath-like manner in one to several layers.
(D) Chloroplasts of bundle sheath cells possess well-developed grana lamellae.

Q.13 **Statement I :** In the photorespiration pathway, there is neither synthesis of sugar nor the ATP formation takes place.
Statement II : Release of CO_2 with ATP utilisation takes place in photorespiration.
(A) Statement I is incorrect II is correct
(B) Statement II is incorrect I is correct
(C) Both I and II are incorrect
(D) Both I and II are correct

Q.14 Read the following statements and select the correct ones.
(i) PS I is involved in non-cyclic photophosphorylation only.
(ii) PS II is involved in both cyclic and non-cyclic photophosphorylation.
(iii) Stroma lamellae membranes possess PS I only, whereas grana lamellae membranes possess both PS I & PS II.
(A) (i) only (B) (ii) only
(C) (iii) only (D) (i), (ii) and (iii)

Q.15 Cyclic photophosphorylation results only in the
(A) formation of ATP
(B) formation of $NADP^+ + H^+$ and ATP
(C) formation of $NAD^+ + H^+$
(D) formation of ADP + Pi

Q.16 Refer the given reaction :
$2H_2O \rightarrow 4H^+ + O_2 + 4e^-$
Where does this reaction take place in the chloroplasts of plants?
(A) Outer surface of thylakoid membrane
(B) Inner surface of thylakoid membrane
(C) In the matrix (stroma)
(D) Intermembrane space

Q.17 **Statement I :** Rate of photosynthesis is independent of duration of exposure of light.
Statement II : At higher light intensities gradually rate of photosynthesis do not show further increase.
(A) Statement I is correct, II is incorrect
(B) Statement II is correct, I is incorrect
(C) Both statements are correct
(D) Both statements incorrect

Q.18 Match the following columns.

	Column I	Column II
(a)	C_3-plants	(i) Calvin cycle
(b)	C_4 -plants	(ii) Hatch and Slack pathway

Codes
(A) (a) – (i), (ii) ; (b) – (i)
(B) (a) – (i) ; (b) – (i), (ii)
(C) (a) – (ii), (b) – (i)
(D) (a) – (i), (b) – (ii)

Q.19 The ATPase enzyme consists of
I. F_0 II. F_1 III. F_2
Select the correct option.
(A) I and III (B) I and II
(C) Only I (D) II and III

Note (Q.20-Q.29) :
Each questions contain STATEMENT-1 (Assertion) and STATEMENT-2 (Reason). Each question has 4 choices (A), (B), (C) and (D) out of which ONLY ONE is correct.
(A) Statement-1 is True, Statement-2 is True, Statement-2 is a correct explanation for Statement-1.
(B) Statement-1 is True, Statement-2 is True; Statement-2 is NOT a correct explanation for Statement-1.
(C) Statement - 1 is True, Statement- 2 is False.
(D) Statement -1 is False, Statement -2 is False.

Q.20 **Statement 1 :** Six molecules of CO_2 and twelve molecules of $NADPH^+ + H^+$ and 18 ATP are used to form one hexose molecule.
Statement 2 : Light reaction results in formation of ATP and $NADPH_2$.

Q.21 **Statement 1 :** There is a decrease in photosynthesis, if the photosynthetic cells are illuminated by light of P_{680} nm or more wavelength.
Statement 2 : In red drop phenomenon the rate of photosynthesis decreases.

Q.22 **Statement 1 :** Cyclic pathway of photosynthesis first appeared in some eubacterial species.
Statement 2 : Oxygen started accumulating in the atmosphere after the non-cyclic pathway of photosynthesis evolved.

Q.23 **Statement 1:** Photorespiration interferes with the successful functioning of Calvin cycle.
Statement 2 : Photorespiration oxidises ribulose-1, 5 biphosphate which is an acceptor of CO_2 in Calvin cycle.

Q.24 **Statement 1 :** Each molecule of ribulose-1, 5-bisphosphate fixes one molecule of CO_2.
Statement 2 : Three molecules of NADPH and two ATP are required for fixation of one molecule of CO_2.

Q.25 **Statement 1 :** C_4 Photosynthetic pathway is more efficient than the C_3 pathway.
Statement 2 : Photorespiration is suppressed in C_4 plants.

Q.26 **Statement 1 :** The movement of photosynthates is unidirectional.
Statement 2 : Movement of photosynthates occurs with the water.

Q.27 **Statement 1 :** In photosynthesis, during ATP synthesis, protons accumulate in the lumen of thylakoid.
Statement 2 : In respiration, during ATP synthesis, protons accumulate in the intermembranal space of mitochondria.

Q.28 **Statement 1 :** Carboxylation is the most crucial step of Calvin cycle where CO_2 is utilized for the carboxylation of RuBP.
Statement 2 : This reaction is catalysed by the enzyme RuBisCO which results in the formation of two molecules of 3-PGA.

Q.29 **Statement 1 :** Crassulacean acid metabolism occurs in succulent plants which grow in xeric conditions.
Statement 2 : Stomata are generally sunken in succulent plants.

EXERCISE - 4 (PREVIOUS YEARS AIPMT/NEET EXAM QUESTIONS)

Choose one correct response for each question.

Q.1 Anoxygenic photosynthesis is characteristic of **[AIPMT 2014]**

(A) *Rhodospirillum* (B) *Spirogyra*
(C) *Chlamydomonas* (D) *Ulva*

Q.2 Chromatophores take part in: **[RE-AIPMT 2015]**

(A) Growth (B) Movement
(C) Respiration (D) Photosynthesis

Q.3 In photosynthesis the light-independent reactions take place at **[RE-AIPMT 2015]**

(A) Photosystem-I (B) Photosystem-II
(C) Stromal matrix (D) Thylakoid lumen

Q.4 In a chloroplast the highest number of protons are found – **[NEET 2016 PHASE 1]**

(A) Stroma
(B) Lumen of thylakoids
(C) Inter membrane space
(D) Antennae complex

Q.5 A plant in your garden avoids photorespiratory losses, has improved water use efficiency, shows high rates of photosynthesis at high temperatures and has improved efficiency of nitrogen utilisation. In which of the following physiological groups would you assign this plant? **[NEET 2016 PHASE 1]**

(A) C_3 (B) C_4
(C) CAM (D) Nitrogen fixer

Q.6 Emerson's enhancement effect and Red drop have been instrumental in the discovery of **[NEET 2016 PHASE 1]**

(A) Photophosphorylation and non-cyclic electron transport.
(B) Two photosystems operating simultaneously.
(C) Photophosphorylation and cyclic electron transport.
(D) Oxidative phosphorylation.

Q.7 The process which makes major difference between C_3 and C_4 plants is **[NEET 2016 PHASE 2]**

(A) Glycolysis (B) Calvin cycle
(C) Photorespiration (D) Respiration

Q.8 Phosphonol pyruvate (PEP) is the primary CO_2 acceptor in: **[NEET 2017]**

(A) C_3 plants (B) C_4 plants
(C) C_2 plants (D) C_3 and C_4 plants

Q.9 With reference to factors affecting the rate of photosynthesis, which of the following statements is not correct? **[NEET 2017]**

(A) Light saturation for CO_2 fixation occurs at 10% of full sunlight.
(B) Increasing atmospheric CO_2 concentration upto 0.05% can enhance CO_2 fixation rate
(C) C_3 plants responds to higher temperatures with enhanced photosynthesis while C_4 plants have much lower temperature optimum.
(D) Tomato is a greenhouse crop which can be grown in CO_2 - enriched atmosphere for higher yield.

Q.10 Oxygen is not produced during photosynthesis by **[NEET 2018]**

(A) *Cycas* (B) *Nostoc*
(C) Green sulphur bacteria (D) *Chara*

Q.11 Which is not a product of light reaction of photosynthesis **[NEET 2018]**

(A) NADPH (B) NADH
(C) ATP (D) Oxygen

ANSWER KEY

EXERCISE-1 (SECTION-1&2)

(1) (A) **(2)** (A) **(3)** (C) **(4)** (D)
(5) (A) **(6)** light **(7)** chemical
(8) ATP **(9)** NADPH **(10)** CO_2
(11) glucose **(12)** Calvin **(13)** thylakoids
(14) stroma **(15)** ribulose bisphosphate
(16) carbon-fixation **(17)** rubisco
(18) 3-phosphoglycerate **(19)** ATP
(20) NADPH **(21)** light-dependent
(22) 3-phosphoglyceraldehyde
(23) three **(24)** six **(25)** five
(26) ribulose bisphosphate **(27)** one
(28) glucose **(29)** six
(30) two

EXERCISE - 1 [SECTION-3 & 4]

Q	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55
A	D	D	B	C	B	D	C	C	D	B	C	B	A	C	A	A	A	A	B	A	A	D	A	B	D
Q	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
A	A	B	D	B	B	C	D	D	A	A	C	A	B	C	C	D	B	D	B	C	D	B	D	B	A
Q	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
A	D	C	C	C	B	C	B	B	B	C	A	C	D	A	B	A	A	C	D	B	B	A	D	B	A
Q	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130
A	D	A	C	B	D	C	A	A	A	B	D	D	D	D	B	D	D	A	C	C	A	D	A	C	B
Q	131	132	133	134	135	136	137																		
A	A	D	B	C	A	D	C																		

EXERCISE - 2

Q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
A	A	D	B	B	C	D	A	C	D	A	D	C	B	B	D	B	C	A	A	A	B	D	B	B	C
Q	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
A	C	C	A	C	A	B	B	C	A	A	C	D	B	C	B	D	D	A	D	C	B	B	D	D	A
Q	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70					
A	C	B	B	A	D	A	C	C	C	C	C	B	A	D	B	D	D	D	A	D					

EXERCISE - 3

Q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
A	B	B	B	B	D	C	D	B	D	A	B	D	D	C	A	B	B	B	B	B	B	B	A	C	A
Q	26	27	28	29																					
A	A	B	B	B																					

EXERCISE - 4

Q	1	2	3	4	5	6	7	8	9	10	11
A	A	D	C	B	B	B	C	B	C	C	B

SOLUTIONS

EXERCISE-1

(1) (A) **(2)** (A) **(3)** (C) **(4)** (D)
(5) (A) **(6)** light **(7)** chemical
(8) ATP **(9)** NADPH **(10)** CO_2
(11) glucose **(12)** Calvin **(13)** thylakoids
(14) stroma **(15)** ribulose bisphosphate
(16) carbon-fixation **(17)** rubisco
(18) 3-phosphoglycerate **(19)** ATP
(20) NADPH **(21)** light-dependent
(22) 3-phosphoglyceraldehyde
(23) three **(24)** six **(25)** five
(26) ribulose bisphosphate **(27)** one
(28) glucose **(29)** six
(30) two **(31)** (D)

(32) **(D).** The exposed part of the leaf tested positive for starch while the portion that was in the tube, tested negative. This showed that CO_2 is required for photosynthesis.

(33) **(B).** The rate of Photosynthesis is higher in red light.

(34) (C) **(35)** (B)

(36) **(D).** J-wax cuticle, K-Palisade mesophyll, L-Spongy mesophyll, M-wax cuticle, N-Guard cell with chloroplast.

(37) **(C).** Green light is ineffective in stomatal opening.

(38) **(C).** If light is absorbed, it is not reflected. Only reflected colors are seen. The graph shows that red and blue are most absorbed and that green is most reflected. Therefore the color of the pigment is green.

(39) **(D).**

(40) **(B).** Plant A is not affected by the increase in the concentration of oxygen in the air because in C-4 plants, PEP carboxylase does not react with oxygen. Plant B is a C-3 plant because the increased oxygen levels cause the plant to undergo photo respiration and to carry out less photosynthesis.

(41) **(C).** Chloroplasts are green plastids which function as the site of photosynthesis in eukaryotic photoautotrophs. A chloroplast consists of 3 parts - envelope, matrix and thylakoids. A chloroplast is covered by an envelope made up of two smooth membranes. The chloroplast matrix or fluid stroma is similar to cytoplasm in its constitution. It contains DNA, RNA, ribosomes, enzymes for CO_2 assimilation, proteins, starch grains and fat droplets. In the matrix or stroma are embedded a number of flattened membranous sacs called thylakoids or lamellae. At places the thylakoids are aggregated to form stacks of discs called grana. A granum may have 20-50 thylakoid discs.

(42) **(B).** Light reactions (or photochemical phase) of photosynthesis mainly occur on the grana thylakoids. Dark reactions (or biosynthetic phase) which involve synthesis of carbohydrates by CO_2 fixation, occur in the stroma (or matrix) of chloroplasts. The chloroplast matrix of higher plants stores starch temporarily in the form of starch granules.

(43) **(A).** $6\ CO_2 + 12\ H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light energy}} C_6H_{12}O_6 + 6O_2 + 6\ H_2O$

(44) **(C).** Joseph Priestley observed that a candle burning in a closed, bell jar, soon gets extinguished. Similarly, a mouse would soon suffocate in a closed space. He concluded that a burning candle or an animal that breathe the air, both somehow, damage the air.
But when he placed a mint plant in the same bell jar, he found that the mouse stayed alive and the candle continued to burn. Priestley hypothesised that plants restore the air whatever breathing animals and burning candles remove.

(45) **(A).** In the experiment for starch synthesis in green leaves, two leaves, a variegated leaf or a leaf that was partially covered with black paper and other one that was exposed to light were taken. On testing these leaves for starch, it was clear, that photosynthesis had occurred only in the green parts of the leaves in the presence of light.

(46) (A) **(47)** (A)

(48) **(A).** Julius von Sachs provided evidence for the production of glucose when plants grow. Glucose is usually stored as starch. His later studies showed that the green substance in plants (chlorophyll as we know it now) is located in special bodies (later called chloroplasts) within plant cells.
He found that the green parts in plants are where glucose made, and that the glucose is usually stored as starch.

(49) **(B).** TW Engelmann (1843-1909) performed an interesting experiment using a prism. He split light into its spectral components and then illuminated a green alga. *Cladophora*, placed in a suspension of aerobic bacteria The bacteria were used to detect the sites of O_2 evolution. He observed that the bacteria accumulated mainly in the region of blue and red light of the split spectrum. A flrst action spectrum of photsynthesis was thus described.

(50) **(A).** Cornelius van Niel (1897-1985) who based his studies on purple and green bacteria, demonstrated that photosynthesis is essentially a light dependent reaction in which hydrogen from a suitable oxidisable compound reduces carbon dioxide to carbohydrate. This can be expressed by

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

In green plants, H_2O is the hydrogen donor and is oxidised to O_2 photosynthesis. Some organism do not release O_2 during photosynthesis. When H_2S, instead is the hydrogen donor for purple and sulphur bacteria, the oxidation product is sulphur or sulphate depending on the organism and not O_2, Hence, he inferred that O_2 evolved by green plant comes from H_2O, not from carbon dioxide.

(51) (A) **(52)** (D) **(53)** (A)

(54) **(B).** Chloroplasts are found in the mesophyll cells of the leaves. Leaves have a maximum number of chloroplasts.

(55) **(D).** A chromatographic separation of the leaf pigment shows that the colour that we see in leaves is not due to the single pigment but due to four pigments. They are
Chlorophyll-a (bright or blue green in chromatogram),
Chlorophyll-b (yellow green),
Xanthophyll (yellow),
Carotenoids (yellow to yellow orange).

(56) **(A).** In the matrix or stroma, there are embedded a number of flattened membranous sacs called thylakoids or lamellae. Membranes of thylakoids are called fret membranes. They are made up of both proteins and unsaturated lipids, roughly in the ratio of 50 : 50.

(57) **(B).** Chlorophyll a is the primary photosynthetic pigment, which is bluish green in the pure state. It has an empirical formula of $C_{55}H_{72}O_5N_4Mg$ and molecular weight of 893. It absorbs more red wavelength of light than violet-blue. It is soluble in a number of organic solvents such as petroleum ether.

(58) **(D).** The membranous system is responsible for trapping the light energy that make ATP and NADPH necessary for the starch synthesis.

(59) **(B).** Accessory pigments absorb light and transfer it to chlorophyll-a.

(60) **(B).** Grana are the stacks of thylakoids, which contains photosynthetic pigments therefore, grana are the site of light reaction and stroma are the site of dark reaction.

(61) **(C).** Maximum number of chloroplast is found in leaves.

(62) **(D).** Chlorophyll a is found in almost all photosynthetic plants except bacteria. It is called primary photosynthetic pigment because it performs primary reactions of photosynthesis which involve conversion of light energy into chemical energy. Other photosynthetic pigments like chlorophyll b, xanthophylls and carotenes are called accessory pigments. They absorb light energy of different wavelengths, broaden the spectrum of light absorption and hand over the energy to chlorophyll a through electron spin resonance and also protect chlorophyll a from photo-oxidations.

(63) (D). Pigments are substances that have an ability to absorb light at specific wavelength. Among all pigments, chlorophyll-a absorb the maximum wavelength in the blue and red region.
In these region, the chlorophyll-a does the maximum photosynthesis. Thus, chlorophyll-a is called the main photosynthetic pigment.

(64) (A).

(65) (A). Water provides electrons to the light dependent reaction.

(66) (C). In order to carry on photosynthesis, green plants need a supply of carbon dioxide and a means of disposing of oxygen. In order to carry on cellular respiration, plant cells need oxygen and a means of disposing of carbon dioxide.

(67) (A) **(68)** (B) **(69)** (C)

(70) (C). Photochemical phase, also called light or Hill reaction, occurs inside the thylakoids, especially those of grana region. Photochemical step is dependent upon light. The function of this phase is to produce assimilatory power consisting of reduced coenzyme NADPH and energy rich ATP molecules.

(71) (D). Stroma lamellae lacks both PS-II and NADP reductase due to the occurrence of cyclic photophosphorylation.

(72) (B). The electrons that were moved from photosystem II must be replaced. This is achieved by electrons available due to splitting of water. The splitting of water is associated with the PS-II. Water is split into H^+, O and electrons. This creates oxygen, one of the net products of photosynthesis. The electrons that are needed to replace those removed from photosystem- I are provided by photosystem- II.

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

(73) (D). The complete process of photosynthesis is studied under two phases -photochemical phase and biosynthetic phase. Photochemical phase involves absorption of light energy, photolysis of water with the release of O_2 and production of assimilatory power (i.e., ATP + NADPH). CO_2 fixation occurs during biosynthetic phase of photosynthesis.

(74) (B). The movement of electrons in ETS of photosynthesis is down hill in terms of oxidation reduction or redox potential scale. The electrons are not used up as they pass through the electron transport chain, but they are passed on the pigments of photosystem I. Simultaneously, electrons in the reaction centre of PS-I are also excited, when they receive red light of wavelength 700 nm and are transferred to another acceptor molecule that has greater redox potential. These electrons than are moved down hill again, this time to a molecule of energy rich $NADP^+$. The addition of these electrons reduces the $NADP^+$ to $NADPH + H^+$.

(75) (C). In cyclic photophosphorylation, an electron expelled by the excited photocentre (P_{700}) is returned to it after passing through a series of electron carriers. Its photocentre P_{700} extrudes an electron with a gain of 23 kcal/ mole of energy after absorbing a photon of light (hν). After losing the electron the photocentre becomes oxidised. The expelled electron passes through a series of carriers including X or A_0 (a special P_{700} chlorophyll molecule), A, (a quinone), FeS complexes (FeS_x,FeS_A,FeS_B), ferredoxin (Fd), plastoquinone (PQ),cytochrome b-f complex and plastocyanin (PC) before returning to photocentre. While over the cytochrome complex, the electron energises passage of protons to create a proton gradient for synthesis of ATP from ADP and inorganic phosphate.

(76) (D). Along with the NADPH produced by the movement of electrons, The ATC will be used immediately in the biosymmetric reaction taking place in the stroma, responsible for fixing CO_2 (reduction) synthesis of sugars.

(77) **(B).** Scheme of transfer of electrons, starting from the PS-II, uphill to the acceptor, down the electron transport chain to PS-I, excitation of electrons, transfer to another acceptor and finally down hill to $NADP^+$ causing it to be reduced to $NADPH + H^+$ is called the Z scheme, due to its characteristic shape.
This shape is formed when all the carriers are placed in a sequence on a redox potential.scale.

(78) **(D).** Proton gradient is important because it is the break down of this gradient that leads to release of energy. The gradient is broken down due to movement of protons across the membrane to the stroma through the transmembrane channel of the F_0 of the ATPase. The energy released during the breaking down of proton gradient is used in formation of ATP.

(79) **(B).** The process by which ATP is synthesized by cells (in mitochondria and chloroplasts) is named as phosphorylation Photophosphorylation is the synthesis of AlP from ADP and inorganic phosphate (Pi) in the presence of light Photophosphorylation is of two main types -Cyclic and non-cyclic photophos-phorylation.
Oxidative phosphorylation is the synthesis of energy rich ATP molecules with the help of energy liberated during oxidation of reduced co-enzymes (NADH and $FADH_2$) produced in respiration. It occurs in mitochondrion and the enzyme required for this synthesis is called ATP synthase.

(80) **(A).** A possible location for the cyclic phosphorylation is the stroma lamellae because stroma lamellae lacks PS-II as well as the NADP reductase enzyme.

(81) **(D).** Light reaction starts when solar radiation or light falls on the PS-II. Light reaction is also called photochemical phase, which includes light absorption, water splitting, oxygen release and formation of high energy chemical intermediates like ATP and NADPH.

(82) (C) **(83)** (C) **(84)** (C)

(85) **(B).** Cyclic phosphorylation occurs only when wavelength beyond 680 nm is available for excitation.

(86) **(C).**

(87) **(B).** Light reaction begins with the PS-II. In photosystem-II the reaction centre chlorophyll-a absorbs 680 nm wavelength of red light causing electrons to become excited and jump into orbit further from the nucleus. These electrons are picked up by an electron acceptor, which passes them to an electron system consisting of cytochromes.

(88) **(B).** ATP is synthesised by cells (in mitochondria and chloroplasts) and the process is named as phosphorylation. Photophosphorylation is the synthesis of ATP from ADP and inorganic phosphate in the presence of light. When the two photosystems work in a series, first PS-II and then the PS-I, a process called non-cyclic photophos-phorylation occurs. The two photo systems are connected through an electron transport chain, as seen earlier- in the Z scheme. Both ATP and NADPH+ H^+ are synthesised by this kind of electron flow. When only PS-I is functional, the electron is circulated within the photosystem and the phosphorylation occurs due to the cyclic flow of electrons.

(89) **(B).** The chemiosmotic hypothesis explains the ATP synthesis mechanism. Like in respiration, in photosynthesis too, ATP synthesis is linked to the development of proton gradient across the membrane. This time these are the membranes of the thylakoid. There is one difference that in photosynthesis the proton accumulation is towards the inside of membrane, i.e., in the lumen. In respiration, proton accumulate in the intermembrane of the mitochondria when electrons move through the ETS.

(90) **(C).** The light-independent reactions of the Calvin cycle can be organized into three basic stages: fixation, reduction, and regeneration. In the stroma, in addition to CO_2,two other components are present to initiate the light-independent reactions: an enzyme called ribulose bisphosphate carboxylase (RuBisCO) and three molecules of ribulose bisphosphate (RuBP).

(91) **(A).** Calvin cycle requires rubisco, RUBP and 3PGAL but not the pigments.

(92) **(C).** Most 3PGAL go back into the cycle to form RUBP.

(93) **(D).** In photosynthesis, hydrogen is transferred from the light reactions to dark reactions by NADP.

(94) **(A).** In the first step CO_2 is accepted by a 5- carbon molecule, ribulose -1,5 biphosphate (RuBP) and 2 molecules of 3-carbon compound that is 3- phosphoglycerate (PGA) are formed. This reaction is catalysed by an enzyme called Rubisco-Ribulose biphosphate carboxylase oxygenase. Formation of PGA is called carboxylation.

(95) **(B).** Calling the biosynthetic phase as the dark reaction is misnomer because without the light reaction, the dark reaction cannot sustain for long. For the sake of simplicity, it is been called dark reaction.

(96) **(A).** RuBP carboxylase oxygenase (RuBisCo).

(97) **(A).** Melvin Calvin used radioactive ^{14}C in algal photosynthesis, which led to the discovery that the first CO_2 fixation product was a 3-carbon organic acid. He also contributed to working out the complete biosynthetic pathway; hence it was called Calvin cycle after him. The first product identified was 3-phosphoglyceric acid or PGA. For this, he was awarded Nobel Prize.

(98) **(C).** Biosynthetic phase (Dark or Blackman's reaction) catalyses the assimilation of CO_2 to carbohydrates. These reactions occur in stroma or matrix of chloroplasts and all the enzymes required for the processes are present in the stroma/matrix of chloroplasts. These reactions do not require light, instead assimilatory power (ATP and NADPH) produced during photochemical (light) phase is used in fixation and reduction of CO_2, However, this should not be construed to mean that they occur in darkness or that they are not light dependent.

(99) **(D).** Synthesis of sugars or carbohydrates is called the biosynthetic phase of photosynthesis. This process does not directly depends on the presence of light but is dependent on the products of the light reaction, i.e., ATP and NADPH, besides CO_2 and H_2O. This could be verified immediately after light becomes unavailable. The biosynthetic process continues for sometime and then stops. If then, light is made available, the synthesis starts again.

(100) **(B).** The Calvin cycle proceeds in three stages (A) carboxylation, during which CO_2 combines with ribulose 1, 5-bisphosphate; (B) reduction, during which carbohydrate are formed at the expense of the photochemically made ATP and NADPH; and (C) regeneration during, which CO_2 acceptor ribulose 1, 5-bisphosphate is formed again so that the cycle continues. Regeneration of the CO_2 acceptor molecule, RuBP is crucial if the cycle is to continue uninterrupted. The regeneration steps require one ATP for phosphorylation to form RuBP.

(101) **(B).** For the ease of understanding Calvin cycle can described under three stages.

(i) Carboxylation is the fixation of CO_2 into stable organic intermediate.

(ii) Reduction is a series of reactions that lead to the formation of glucose.

(iii) Regeneration of CO_2 acceptor molecule, RuBP is main part of this stage.

(102) **(A).** For every CO_2 molecule entering the Calvin cycle, 3 molecule of ATP and 2 molecule of NADPH are required. The difference in the number of ATP and NADPH used in dark reaction is overcome by cyclic phosphorylation.

(103) **(D).** If light becomes unavailable then the biosynthetic phase continues for sometime and then stops.

(104) **(B).** **Reduction :** These are series of reactions that lead to the formation of glucose. The steps involved are: utilisation of 2 molecules of ATP for phosphorylation and molecules of NADPH for the reduction per CO_2

molecule fixed for the fixation of six molecules of CO_2, 6 turns cycle are required for the removal of one molecule glucose from the pathway.

(105) (A). C_4 (Hatch and Slack) cycle :
The primary CO_2 acceptor is Phosphoenol pyruvic acid (PEP, a 3 Carbon compound).

(106) (D). Examples of C_4 species are the economically important crops corn or maize (Zea mays), sugarcane (Saccharum officinarum), sorghum (Sorghum bicolor), and millets, as well as the switchgrass (Panicum virganum) which has been utilized as a source of biofuel.

(107) (A). C_4 plants are adapted to hot and dry climate.

(108) (C). In C_4 plants, the initial acceptor of CO_2 is phosphoenol pyruvic acid or PEP, a 3-carbon compound. It combines with CO_2 in presence of an enzyme Phosphoenol pyruvate carboxylase (PEP carboxylase) and forms a C_4 acid, oxaloacetic acid (OAA).

(109) (B). C_4 Plants
1. Only in tropical plants.
2. Plants that use the cycle can be mesophytic
3. Photoactive Stomata
4. Photorespiration: less or negligible
5. Kranz anatomy
6. 12 NADPH and 30 ATPs are required.
7. Double carbon dioxide fixation
8. Atmosphere CO_2 acceptor- PEP(In mesophyll cell) and Metabloic CO_2 acceptor-RUBP(In bundle sheath cell)
9. First stable product OAA (Oxalo acetic acid)
10. First enzyme involved PEP Carboxylase
11. CO_2 compensation point: 10PPM

(110) (D). List of families in the angiosperms having at least one C_4 member.

Monocots	Family
	1. Cyperaceae
	2. Hydrocharitaceae
	3. Gramineae

(111) (C). C_4 -plants are special. They have a special type of leaf anatomy, they tolerate higher temperature, they show a response to high light intensities, they lack a process called photorespiration and have greater productivity of biomass.

(112) (A). C_4-plants have Kranz anatomy, which includes bundle sheath cells and mesophyll cells. In case of C_4 plants, the primary CO_2 acceptor is a 3-carbon molecule, i.e., phosphoenol pyruvate and is present in the mesophyll cells.

(113) (A). In mesophyll cells the PEP carboxylase is present and RuBisCo is absent.
In bundle sheath cells the RuBisCo is present and PEP carboxylase is absent.

(114) (A). In C_4 plants, the first stable photosynthetic product is a 4-carbon compound i.e., oxaloacetic acid (OAA), which is formed by initial fixation of CO_2 by the carboxylation of phosphoenol pyruvate in the mesophyll cells. So, when radioactive $^{14}CO_2$ is introduced into the reaction, it is first incorporated into the OAA.

$$PEP + {}^{14}CO_2 + H_2O \xrightarrow{\text{PEP carboxylase}} OAA + H_3PO_4$$

In a CAM plant, although the first product formed is OAA, but here the initial CO_2 fixation occurs at night.

(115) (B). CO_2 assimilation during photosynthesis generally takes place in two ways in plants
(i) C_3 pathway Those plants in which the first product of CO_2 fixation is a C_3 acid (PGA), i.e., the C_3 pathway.
(ii) C_4 pathway : Those plants in which the first product is C_4 acid (OAA), i.e., the C_4 pathway.

(116) (D). In C_4-plants, bundle sheath chloroplast are highly efficient in carbon dioxide fixation.

(117) (D).

(118) (D). Plants that are adapted to dry tropical regions generally have the C_4 pathway. Though these plants have the C_4-oxaloacetic acid as the first CO_2 fixation product they use the C_3 pathway or the Calvin cycle as the main biosynthetic pathway.

(119) (D). In bundle sheath cell C_3-cycle is performed, so these cells have high number of RuBisCo as compared to other cells.

(120) **(B).** In C_4-plants the initial fixation of carbon dioxide occurs in mesophyll cell. The primary acceptor of CO_2 is phosphoenol pyruvate or PEP. It combines with carbon dioxide in presence of PEP carboxylase or PEPcase to form oxaloacetic acid or oxaloacetate.

(121) **(D).** Photorespiration in C_3 plants starts from phosphoglycolate.

(122) **(D).** The site for photorespiration is chloroplast. RuBP carboxylase function as oxygenase and instead of fixing carbon dioxide, it convert oxidase ribulose 1-5 biphosphate (RuBP) to produce phosphoglycerate and phosphoglycolate.

$$RuBP + O_2 \xrightarrow[\text{Oxygenase}]{\text{RuBP}} PGA + \text{Phosphoglycolate}$$

(123) **(A).** In C_3-plants, photorespiration takes place but this pathway is absent in C_4-plants.

(124) **(C).** In the photorespiration pathway, there is neither synthesis of sugar nor of ATP. Rather, it results in the release of CO_2 with the utilisation of ATP.

(125) **(C).** RuBisCo is the most abundant enzyme in the world. It is characterised by the fact that active sites can bind to both CO_2 and O_2, This binding is competitive. It is the relative concentration of O_2 and CO_2 that determines, which of two (CO_2 and O_2) will bind to enzyme.

(126) **(A).** The substrate for photorespiration is glycolate, which is formed in the chloroplast, due to the oxygenase activity of RuBisCo.

(127) **(D).** Photorespiratory pathway (or C_2 pathway) results in the release of CO_2 with the utilisation of ATP. In the photorespiratory pathway, there is no synthesis of ATP or NADPH.

(128) (A) **(129)** (C)

(130) **(B).** C_3 plants

1. Found in all photosynthetic plants.
2. Plants that use the cycle can be hydrophytic, mesophytic and xerophytic.
3. Photoactive Stomata
4. High rate of Photorespiration
5. Normal Leaf anatomy
6. For the synthesis of glucose molecule or $6CO_2$ fixation: 12 NADPH and 18 ATPs are required.
7. Single CO_2 fixation occurs
8. Primary CO_2 atmospheric acceptor RUBP
9. First stable product 3PGA
10. First enzyme involved RUBISCO
11. Carbon dioxide compensation point: 30-70PPM.

(131) **(A).**

(132) **(D).** A limiting factor is defined as a factor which is deficient to such an extent that increase in its magnitude directly increases the rate of the process.

The effect of limiting factors was studied by Blackman in 1905. He formulated the principle of limiting factors which states that when a process is conditioned as to its rapidity by a number of separate factors, the rate of the process is limited by the pace of the slowest factor.

In the given graph, rate of photosynthesis initially increases with an increase in light intensity (region A) but soon it levelled off. Thus, initially light intensity was limiting the rate of photosynthesis. However, when light intensity was present in sufficient amounts (region C), rate of photosynthesis did not increase further. This is due to the fact that in region C. some other factor (e.g. CO_2 concentration) became the limiting factor. At this region, the rate of photosynthesis could be further enhanced only by the increase in availability of other limiting factor (e.g. CO_2).

(133) (B) **(134)** (C) **(135)** (A)

(136) **(D).** The process of photosynthesis is influenced by several factors, which include both internal (plant) and external (environmental) factors.

The plant factors include the number, size, age and orientation of leaves, presence or absence of hormones (cytokinins and gibberellins increase the rate of photosynthesis whereas abscisic acid reduces the same), leaf anatomy (size, structure, position and frequency of stomata, thickness of epidermis and cuticle, etc.), amount of chlorophyll, etc. The external factors would include the availability of sunlight, temperature, concentration of CO_2 and O_2 and water.

(137) (C)

EXERCISE-2

(1) **(A).** A decrease in atmospheric carbon dioxide level reduce the rate of photosynthesis.

(2) (D) **(3)** (B) **(4)** (B)

(5) **(C).** In C_3 plants, bundle sheath cells usually do not contain chloroplasts and the whole C_3 cycle operates in mesophyll cells of leaves. In C_4 plants showing Hatch-Slack cycle however, initial fixation of CO_2 occurs in mesophyll cells followed by final fixation in bundle sheath cells.

(6) (D) **(7)** (A) **(8)** (C) **(9)** (D)

(10) (A) **(11)** (D) **(12)** (C)

(13) **(B).** All of the choices are required for photosynthesis to occur except oxygen, which is released as a by-product of photosynthesis.

(14) **(B).** In C-3 plants, the Calvin cycle occurs in all photo-synthetic cells in both the palisade and mesophyll layers. However, in C-4 plants, the light reactions occur in only the mesophyll cells while the Calvin cycle occurs in the bundle-sheath cells.

(15) (D)

(16) **(B).** Each Calvin cycle makes 2 molecules of 3PGAL.

(17) (C)

(18) (A)

(19) **(A).** In the process of photosynthesis, the phosphorylation of ADP to form ATP using the energy of sunlight is called photophosphorylation.

(20) (A)

(21) (B)

(22) **(D).** The first step in photosynthesis is excitement of an electron of chlorophyll by a photon of light.

(23) **(B).** $ADP + Inorganic\ PO_4 \xrightarrow{\text{Light energy}} ATP$

(24) (B) **(25)** **(C)** **(26)** (C)

(27) **(C).** Anthocyanins are water-soluble vacuolar pigments that may appear red, purple, or blue depending on the pH. They occur in all tissues of higher plants, including leaves, stems, roots, flowers, and fruits.

(28) **(A).** Number of ATP molecules required for regeneration phase of' RuBP during synthesis of 1 glucose molecule 6.

(29) (C) **(30)** (A) **(31)** (B) **(32)** (B)

(33) **(C).** During the photosynthesis within chloroplast protons in the stroma decreases in number, while in lumen there is accumulation of protons. This creates a proton gradient across the thylakoid membrane as well as a measurable decrease in pH (acidic) in the lumen.

(34) **(A).**

(35) **(A).** Within the chloroplast, there is the membranous system (grana, stroma lamellae) and fluid, which is called stroma.

(36) **(C).** During the light reaction, the splitting of water gives two proton, one oxygen and two electrons. Protons are used in the formation of protein gradient across the thylakoid membrane. Oxygen is liberated as byproduct. Electrons goes to the PS-II and to the electron transport chain.

(37) **(D).** Excited simultaneously with PS-II (P_{680}).

(38) **(B).** Main biosynthetic pathway for CO_2 fixation in C_4-plant is C_3 pathway.

(39) **(C).** Water is one of the reactant in the light reaction. The effect of water on photosynthesis is seen in the stress condition when water availabtlity is very low. Water is also produced in dark reaction of photosynthesis. Water stress causes the stomata to close hence reducing, the availability.

(40) **(B).**

(41) **(D).** The whole scheme of transfer of electrons, starting from the PS II, uphill to the acceptor, down the electron transport chain to PSI, excitation of electrons, transfer to another acceptor and finally down hill to $NADP^+$ causing it to be reduced to $NADPH + H^+$

is called as the Z scheme, due to its characteristic shape. This shape is formed when all the carriers are placed in a sequence on the redox potential scale.

(42) **(D).** The Russian botanist Mikhail Tswett is credited with the original development of a separation technique that we now recognise as a form of chromatography. In 1903, he reported the successful separation of plant pigments by using a column of calcium carbonate.

(43) **(A).** Steps that causes proton gradient to develop during photophosphorylation are

(i) protons or hydrogen ions that are produced by the splitting of water accumulates within the lumen of the thylakoids.

(ii) As electrons move through the photosystems, protons are transported across the membrane. This happens because the primary acceptor of electron, which is located towards the outer side of the membrane transfers its electrons not to an electron carrier but to an H^+ carrier. Hence, this molecule removes a proton from stroma, while electrons transporting.

(iii) The NADP reductase enzyme is located on the stroma side of the membrane. Along with electron, reduction of $NADP^+$ to NADPH + H^+ takes place. By this way, the proton removes from stromal side of the thylakoid.

(44) **(D).** The rate of photosynthesis is very 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 includes the number, size, age and orientation of leaves, mesophyll cells and chloroplast, internal CO_2 concentration and the amount of chlorophyll. The plant or internal factors are dependent on the genetic predisposition and the growth of the plant.

(45) **(C).** The pigments are organised into two discrete photochemical Light Harvesting Completes (LHC) within the Photosystem I (PS-I) and Photosystem II (PS-I). These are named in the sequence of their discovery, and not in the sequence in which they function during the light reaction.
The LHC are made up of hundreds of pigment molecules bound to proteins. Each photosystem has all the pigments (except one molecule of chlorophyll-a) forming a light harvesting system known as antenna.

(46) **(B).**

(47) **(B).** During the dark reaction the acceptor of CO_2 is RuBP (Ribulose 1-5 diphosphate). After accepting, it forms intermediate six carbon compound, which breaks into two three carbon stable compound. It is called 3 PGA.

(48) (D) **(49)** (D)

(50) **(A).** C_4-plants have very little photorespiration because its initial carbon fixation is done by PEP carboxylase not by Rubisco. Beside this, C_4-plant generate their own CO_2 by decarboxylation of C_4 acids in bundle sheath. Due to these reasons, the C_4-plants minimise photorespiration.

(51) **(C).** Non-cyclic photophosphorylation is the normal process of photophosphorylation in which the electron expelled by the excited photocentre does not return to it. Non-cyclic photophosphorylation is carried out in collaboration of both photosystems I and II. Electron released during photolysis of H_2O is picked up by photocentre of PS II called P_{680}. The same is extruded out when the photocentre absorbs light energy ($h\nu$). Electrons released during the photolysis of water are immediately accepted by oxidized reaction centre of PSII (i.e., P_{680}) through an unknown substance Z.

(52) **(B).** The CO_2 formed in the bundle sheath cells decarboxylation of malic acid used in the Calvin cyde that way, C_4-plants have their own CO_2 for the Calvin That's why C_4-plants can perform Calvin cycle even in low CO_2 concentration.

(53) **(B).** The internal factors that affects photosynthesis of plant depends on the genetic predisposition.

(54) **(A).** Only PS-I is involved in cyclic photophosphorylation in the formation of ATP when the electrons move down hill in term of redox potential

(55) **(D).** If thylakoid is punctured, then the interior of the thylakoid is no longer separated from the stroma and this leads to stoppage of ATP synthesis.

(56) **(A).** Biosynthetic phase of photosynthesis depend on the NADPH and ATP. Both are used directly in the synthesis of glucose.

(57) **(C).** PEP carboxylase

(58) **(C).** RuBisCo

(59) **(C).** The C_4 plants respond to higher temperatures and show higher rate of photosynthesis while C_3 plants have a much lower temperature optimum. The temperature optimum for photosynthesis of different plants depends on the habitat that they are adapted to. Tropical plants have a higher temperature optimum than the plants adapted to temperate climates; tropical areas have higher temperature as compared to temperate areas.

(60) **(C).**

(61) **(C).** Malic acid or aspartic acid is translocated to bundle sheath cells through plasmodesmata. Inside the bundle sheath cell they are decarboxylated (malic acid) or deaminated. In case of aspartic acid to form CO_2 and pyruvate.

(62) **(B).** In the Calvin cycle, the RuBP combines with the CO_2 to form 2 molecules of 3 phosphoglyceric acid and the reaction is catalysed by RuBisCo.

$$RuBP + CO_2 \xrightarrow{\text{RuBisCo}} 2 \times 3PGA$$

(63) **(A).** The optimum temperature is 10°C-25°C for C_3 plants and 30°C-45°C for C_4 plants.

(64) **(D).** Chemiosmosis requires a membrane, a proton pump, a proton gradient for making ATP through ATPase enzyme.

(65) **(B).** ATP is synthesised by chloroplast and mitochondria in the cell.

(66) **(D).** RuBP carboxylase oxygenase.

(67) **(D).** In chloroplast, the light reaction occurs in grana and dark reaction in stroma.

(68) **(D).** Kranz anatomy is shown by C_4 plants such as *Sorghum*, sugarcane, maize, *Cyperus rotundus* etc.

(69) **(A).**

Light Harvesting Complex includes

- **Antenna Molecule**
  The antenna molecule absorb light of various wavelengths but shorter than that of photocentre (chlorophyll-a) antenna molecule includes chlorophyll-b xanthophyll.
- **Core Molecule**
  Various pigment molecules in antenna complex absorb different wavelengths of light and transfer it to the core molecule, i.e., chlorophyll-a.

(70) **(D).**

EXERCISE-3

(1) **(B).** Electron excited by PS-I used in the formation of NADPH + H^+. These electrons come ultimately from H_2O through photosynthesis.

(2) **(B).** Rate of photosynthesis usually increases with an increase in temperature upto 40°C. Above this temperature, rate of photosynthesis starts decreasing due to inactivation of enzymes.The minimum temperature at which most plants start photosynthesis is 0°-5°C but it can be as low as –20°C for lichens and –35°C for some gymnosperms. The maximum temperature at which photosynthesis can occur is 55°C in some desert plants and 75°C for hot spring algae. When temperature is increased from minimum to optimum, the rate of photosynthesis doubles for every 10°C rise in temperature.

(3) **(B).** PS·I, NADPH + H^+, stroma

(4) **(B).** Carotenes are hydrocarbons with a general formula of $C_{40}H_{56}$. Red colour of tomato, carrots and chillies is due to carotene called lycopene. The most common carotene is β-carotene. It is converted to vitamin A by animals and human beings.

$$\underset{\beta\text{-carotene}}{C_{40}H_{56}} + 2H_2O \rightarrow \underset{\text{Vitamin A}}{2C_{19}H_{27}CH_2OH}$$

(5) **(D).**

(i) C_3-plant respond well to higher CO_2 concentration by showing increased rate of photosynthesis.

(ii) C_4-plant respond to higher CO_2 concentration by showing increased rate of photosynthesis.

(6) **(C).** $6CO_2^{18} + 12H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} C_6H_{12}O_6^{18} + 6H_2O + 6O_2$ (Carbohydrate)

(7) **(D).** During photosynthesis, the proton accumulation is towards the inside of the membrane, i.e., in the lumen. In respiration, protons accumulate in the intermembrane space of the mitochondria when electrons move through the ETS.

(8) **(B).** DCMU (Dichlorophenyl dimethyl urea) is a herbicide which kills the weeds by inhibiting CO_2 fixation as it is a strong inhibitor of photosystern II (P_{680}). DCMU acts by blocking electron flow at the guanine acceptors of PS II, by competing for the binding site of plastoquinone.

(9) **(D).** Glucose molecule contains-6 carbon. For fixing one carbon (CO_2), Calvin cycle needs 3 ATP and 2 NADPH.
Then for fixing six carbon ($C_6H_{12}O_6$), Calvin cycle needs 18ATP & 12 NADPH.
The net reaction of C_3 dark fixation of CO_2 is 6 RuBP + 6 CO_2 + 18 ATP + 12 NADPH $\rightarrow$ 6RuBP + $C_6H_{12}O_6$ + 18 ADP + 18Pi + 12$NADP^+$

(10) **(A).** Oxygen is a product of photosynthesis. A small quantity of O_2 is essential for photosynthesis to take place. But as O_2 concentration rises, rate of photosynthesis decreases. It may be because (i) Oxygen takes part in oxidation of photosynthetic pigments, intermediates and enzymes in the presence of strong light (photo-oxidation). (ii) Oxygen is a strong quencher of excited state of chlorophyll. Oxygen competes with CO_2 for reducing power. It converts RuBP-carboxylase to RuBP-oxygenase. At very high oxygen concentration, the rate of photosynthesis begins to decline in all plants. This phenomenon is referred to as Warburg effect.

(11) **(B).** In C_4-plants the Calvin cycle takes place in bundle sheath cells.

(12) **(D).** Kranz anatomy is a characteristic of C_4 plants. In Kranz anatomy, the mesophyll is undifferentiated and its cells occur in concentric layers around vascular bundles. Vascular bundles are surrounded by large sized bundle sheath cells which are arranged in a wreath-like manner in one to several layers. The chloroplasts of mesophyll cells are smaller, they have well developed grana and a peripheral reticulum but no starch. Mesophyll cells possess enzyme PEPcase for initial fixation of CO_2, The chloroplasts of the bundle sheath cells are agranal. They possess a peripheral reticulum and starch grains. Bundle sheath cells possess enzyme RuBisCo.

(13) **(D).** Photorespiration does not produce energy or reducing power. Rather, it consumes the energy further. It undoes the work of photosynthesis. It may reduce photosynthesis upto 50%. Therefore, photorespiration is a highly wasteful process. This happens only in C_3-plants.

(14) **(C).** PSI is involved in both cyclic and non-cyclic photophosphorylation. PS II is involved only in non-cyclic photophosphorylation. PS II is present in the appressed (inner) part of grana thylakoids. PS I is located in the non-appressed (outer) part of grana thylakoids as well as stroma thylakoids.

(15) **(A).** During the cyclic phosphorylation, the electrons does not pass to the $NADP^+$ but cycled back to PS-I through electron transport chain.
This cyclic flow hence, results only in the synthesis of ATP but not of NADPH + H^+.
Cyclic photophosphorylation occurs when only light of wavelength beyond 700 nm is available for excitation.

(16) **(B).** The splitting of water is associated with the PS II. Water is split into H^+, [O] and electrons. The electrons needed to replace those removed from photosystem I are provided by photosystem II.

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

Water splitting complex is associated with the PSII, which itself is physically located on the inner side of the membrane of the thylakoid.

(17) **(B).** Rate of photosynthesis is dependent of duration of exposure of light. At higher light intensities, photosynthesis don't show further increase because at that level plant does not need sugar synthesis.

(18) **(B).** In C_4-plants both C_3 pathway (Calvin cycle) and C_4 pathway (Hatch and Slack) occur. Calvin cycle occur in bundle sheath cell and C_4 cycle occur in mesophyll cells.

(19) **(B).** ATPase enzyme consists of

F_0 : It is embeded in the membrane and forms a transmembrane channel that carries out facilitated diffusion across the membrane.

F_1 : It protrudes on the outer surface of the thylakoid membrane on the side that falls stroma. The breaking down of gradient provides enough energy to cause conformational changes in F_1 particle. which makes the enzyme synthesise several molecules of energy packed ATP.

(20) **(B).** Six molecules of CO_2 enter Calvin cycle to produce one hexose molecule whereas 18 ATP, 12 $NADPH^+H^+$ molecules are used up. The light reaction of photosynthesis results in ATP and $NADPH_2$ formation.

(21) **(B).** Although the efficiency of photosynthesis is uniform over most of the spectrum, it declines significantly in the red, i.e., at wavelength of 680 nm and above. This phenomenon is called red drop. However, it was shown by Emerson that if light at 680 nm is supplemented with light of a shorter wavelength (< 600 nm), the quantum efficiency of photosynthesis in the red can be restored to normal.

(22) **(B).** Cyclic pathway of photosynthesis is appeared first in some eubacterial species. It is supposed to be the first evidence of production of ATP in the presence of light. During non-cyclic photophosphorylation photolysis of water takes place. Under the influence of light energy and the catalytic action of chlorophyll, water a substance of low energy value, is split up into oxygen and hydrogen. Oxygen is used in the chloroplast. Non-cyclic photophosphorylation is the only natural process which adds molecular oxygen to the atmosphere.

(23) **(A).** Photorespiration (Photosynthetic carbon oxidative or PCO Cycle) is the light dependent process of oxygenation of ribulose-1, 5-biphosphate (RuBP) and release of CO_2 by the photosynthetic organs of a plant. Under normal conditions, in Calvin cycle, carboxylation of RuBP takes place whereas during photorespiration instead of carboxylation, oxygenation of RuBP takes place. This is due to abnormal behaviour of enzyme RuBisCo, which at high temperature (more than 35°C), functions as oxygenase (instead of carboxylase). Instead of fixing CO_2, it performs oxygenation of RuBP to produce a 3-carbon phosphoglyceric acid (PGA) and a 2-carbon phosphoglycolate. It is the first reaction of photorespiration and can be represented as :

$$\text{RuBP} + O_2 \xrightarrow[\text{oxygenase}]{\text{RuBP}} \text{PGA} + \text{Phosphoglycolate}$$

In this way, photorespiration interferes with the successful functioning of Calvin cycle by causing oxygenation of RuBP instead of carboxylation.

(24) **(C).** Each molecule of ribulose-1, 5-biphosphate fixes one molecule of carbon dioxide with the addition of water, thereby resulting in the formation of two molecules of 3-phosphoglyceric acid (3-PGA).

The fixation and reduction of one molecule of CO_2 requires three molecules of ATP and two of NADPH, coming from the photochemical reactions.

(25) **(A).** C_4 photosynthetic pathway is more efficient than C_3 pathway as C_4 plants can pick up CO_2 even when it is found in low concentration. PEP enzymes shows high affinity for CO_2. C_4 plants contain two types of chloroplast (Kranz anatomy) : bundle sheath chloroplast and mesophyll chloroplast. Bundle sheath cells contain Calvin cycle enzymes. Due to high concentration of CO_2 in bundle sheath cells, RuBP carboxylase works only for Calvin cycle and not for photorespiration.

(26) **(A).** The movement of organic materials in the plant is bidirectional that is, substances are translocated in opposite directions in the stem simultaneously. The movement of photosynthates is independent of water translocation as it takes place through phloem whereas latter takes place through xylem.

(27) **(B).** Chemiosmotic hypothesis for the synthesis of ATP was proposed by Peter Mitchell, 1961 (Nobel Prize in 1978). ATP synthesis is linked to the development of proton gradient across a membrane, which occurs in both photosynthesis as well as respiration. The difference between the two processes is that during photosynthesis, proton accumulation takes place in the thylakoid lumen; whereas during respiration, protons accumulate in the intermembranal space of mitochondria when electrons move through the ETS.

(28) **(B).** Carboxylation is the most crucial step of Calvin cycle where CO_2 is utilized for the carboxylation of RuBP through the use of ATP and NADPH generated by the light reactions. The reaction is catalysed by enzyme RuBisCO. CO_2 combines with RuBP (ribulose-1, 5-biphosphate) to produce a transient intermediate compound called 2-carboxy 3-keto 1,5-biphosphoribotol. The intermediate splits up immediately in the presence of water to form two molecules of 3-phosphoglyceric acid or PGA, which is the first stable product of photosynthesis.

$$\text{RuBP} + CO_2 \xrightarrow[\text{Carboxylase, } Mg^{2+}]{\text{RuBP}}$$

2-carboxy 3-keto 1,5-biphosphoribotol

2-carboxy 3-keto 1,5-biphosphoribotol + $H_2O \rightarrow$ 2PGA

(29) **(B).** Crassulacean acid metabolism is a mechanism of photosynthesis involving double fixation of CO_2 which occurs in succulents belonging to Crassulaceae, Cacti, Euphorbias and some other plants of dry habitats where the stomata remain closed during the daytime and open only at night. The process of photosynthesis is similar to that of C_4 plants but instead of spatial separation of initial PEPcase fixation and final RuBisCo fixation of CO_2, the two steps occur in the same cells but at different times, night and day, e.g. *Sedum, Kalanchoe, Opuntia*. Sunken stomata are deep seated stomata in which subsidiary cells lie above the guard cells.

EXERCISE-4

(1) **(A).** In *Rhodospirillum*, electron donor is organic compound during photosynthesis.

(2) **(D).** Chromatophores contain pigments and they are found in blue green algae for photosynthesis.

(3) **(C).** Light-independent reactions or Dark reactions occur in stroma/ stromal matrix. During these reactions carbon dioxide is reduced to carbohydrates.

(4) **(B).** Proton concentration is higher in the lumen of thylakoid due to photolysis of water, H^+ pumping and NADP reductase activity in stroma.

(5) **(B).** C_4 plants are special, they tolerate higher temperatures, they lack photorespiration and have greater productivity of biomass.

(6) **(B).** Emerson performed photosynthetic experiment on *chlorella*. He provided monochromatic light of more than 680 nm and observed decrease in rate of photosynthesis known as red drop.

Later he provided synchronised light of 680 nm and 700 nm and observed increase in rate of photosynthesis, known as enhancement effect. This experiment led to discovery of two photosystems - PS II and PS I.

(7) **(C).** Photorespiration is present in C_3 plants but absent in C_4 plants.

(8) **(B).** PEP is 3C compound which serves as primary CO_2 acceptor in the mesophyll cell cytoplasm of C_4 plants like maize, sugarcane, Sorghum etc.

(9) **(C).** In C_3 plants photosynthesis is decreased at higher temperature due to increased photorespiration.

C_4 plants have higher temperature optimum because of the presence of pyruvate phosphate dikinase enzyme, which is sensitive to low temperature.

(10) **(C).** Green sulphur bacteria do not use H_2O as source of proton, therefore they do not evolve O_2.

(11) **(B).** ATP, NADPH and oxygen are products of light reaction, while NADH is a product of respiration process.