13. Photosynthesis In Higher Plants

Synthesis of chemical compounds with the aid of radiant energy and especially light which results in the formation of carbohydrates from carbon dioxide and a source of hydrogen (such as water) in the chlorophyll-containing cells (as of green plants) exposed to light.

Sunlight plays a much larger role in our sustenance than we may expect, as all the food we eat and all the fossil fuels we use, the air we breathe, they are all products or by-products of photosynthesis. Photosynthesis converts the radiant energy to forms of energy that can be used by the biological systems.

It is a process in which green parts of the plants synthesize or manufacture complex organic food substances (carbohydrate) using carbon dioxide and water in the presence of sunlight and release oxygen as a by-product. In this process, energy from the sun is converted into chemical energy. It is an anabolic endergonic (requiring energy) and oxido-reduction process.

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

Important -

According to former estimates, only 10% of dry matter is produced by land plants while 90% of it is formed in oceans. However, the present estimates put the productivity of land plants to be 68% of the total.

Study on photosynthesis started around 300 years ago. On the basis of what we have studied in our earlier classes, simple experiments have shown that chlorophyll (green pigment of the leaf), light and CO_2 are required for photosynthesis to occur.

1. Experiment to Demonstrate Light and Chlorophyll is Necessary for Photosynthesis

Take a destarched potted plant having variegated leaves and cover 2-3 leaves with the black paper. Expose the potted plant to sunlight for 1-2 hours. Pluck one covered leaf and one exposed leaf and test them for starch. The covered leaf does not show positive starch test showing that photosynthesis cannot occur in the absence of light. The exposed leaf shows blue and yellow parts where the blue color or positive starch test occurs in the chlorophyll-containing parts.

2. Experiment to Demonstrate Co_2 is Necessary for Photosynthesis (Moll's half leaf experiment) Types of Excretory Products

A part of leaf was enclosed in a test tube containing some KOH soaked cotton (which absorbs CO_2), while the other half of leaf was exposed to air. When the two halves of leaf were tested for starch, it was found that only the exposed part of leaf tested positive for starch. This showed us that CO_2 is required for photosynthesis.

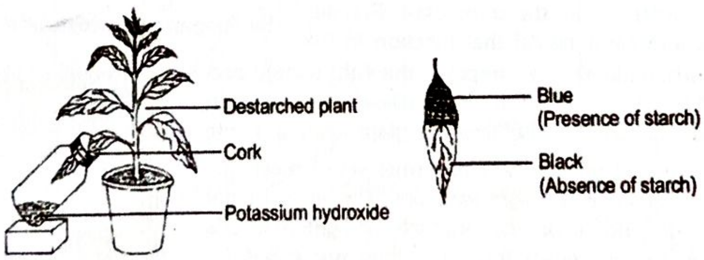


Fig. : Half leaf experiment

3. Historical Timeline of Photosynthesis

(1) Joseph Priestley (1733-1804) in 1770 revealed the essential role of air in the growth of green plants through several experiments. He discovered oxygen in 1774. In an experiment done, Priestley observed that a candle burning in a closed space i.e., a bell jar, soon gets extinguished. Similarly, a mouse would die of suffocation in a closed space (as shown in figure (a) & (b)). Through his experiment, he concluded that both, the burning candle and the mouse damage the air they use. But, when a mint plant was placed in the same bell jar, the mouse stayed alive and the candle continued to burn (as shown in figure (c) and (d)). Thus, Priestley concluded that the plants restore to the air whatever the breathing mouse and the burning candle remove.

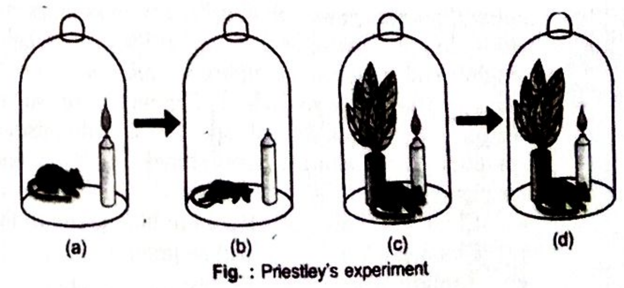


Fig. : Priestley's experiment

(2) small bubbles were formed around the green parts of plant while in the dark, no bubbles were formed. He identified those bubbles to be oxygen. Therefore, he showed that in the presence of sunlight it is only the green parts of the plants that could release oxygen.

(3) Julius von Sachs (1854) found that the green parts in plants is where glucose is made and glucose is usually stored as starch. Later, he showed that the green substance in plants (now called chlorophyll) is located in special bodies (now called chloroplasts) within the plant cells.

(4) T.W. Engelmann (1843-1909) experimented on *Cladophora*. Using a prism he split light into its spectral components and then he illuminated a green alga, *Cladophora*, placed in a suspension of aerobic bacteria. The bacteria were used to detect the sites of oxygen evolution. He found that the bacteria accumulated mainly in the region of blue and red light of the split spectrum. And thus, the first action spectrum of photosynthesis was described.
The empirical equation representing the total process of photosynthesis for organisms evolving oxygen was understood as :

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

Where $[CH_2O]$ represented a carbohydrate.

(5) Cornelius van Niel (1897-1985) A microbiologist, based on his studies of purple and green sulphur bacteria demonstrated that during photosynthesis, hydrogen released from a suitable oxidisable compound reduces carbon dioxide to carbohydrates and inferred that oxygen evolved by the green plants comes from H_2O (water) and not from carbon dioxide. This hypothesis was later proved by using radiosisotopic techniques.

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

Where H_2A is the oxidisable compound (H_2O or H_2S).
Ruben, Kamen et. al. used heavy but non-radioactive stable isotope of oxygen ^{18}O to prove that O_2 evolve during light reaction comes from H_2O and not from CO_2.

4. Sunlight

Sunlight is like a rain of photons of different frequencies. Visible light consists of radiations having a wavelength between 390-760 nm. Part of spectrum used in photosynthesis has a wavelength between 400-700 nm. It is called photosynthetically active radiation (PAR).

5. Chloroplast- Photosynthetic Organ of Cell

Photosynthesis takes place in the green leaves of plants and other parts of plants like stem etc. The most active photosynthetic tissue in higher plants is the mesophyll cells of leaves. Mesophyll cells have many chloroplasts, which contain the specialised light-absorbing green pigments, the chlorophylls.

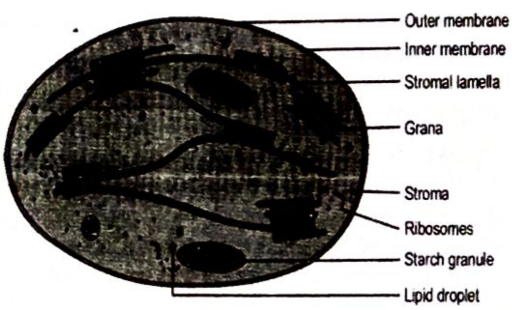


Fig. : Diagrammatic representation of an electron micrograph of a section of chloroplast

- **Internal structure of Chloroplast** : In photosynthetic eukaryotes, photosynthesis occurs in the sub cellular organelle known as the chloroplast. This double membrane-enclosed organelle possesses a third system of membranes called thylakoids. A stack of thylakoids forms a granum. Adjacent grana are connected by unstacked membranes called stroma lamellae. The fluid compartment surrounding the thylakoids, called the stroma. There is a clear division of labour within the chloroplast. Proteins and pigments (chlorophylls and carotenoids) that function in the photochemical events of photosynthesis, i.e., trapping the light energy and synthesis of ATP an NADPH, are embedded in the thylakoid membrane. In stroma, enzymatic reactions incorporate CO_2 into the plant leading to the synthesis of sugar, which in turn forms starch. The former set of reactions, since they are directly light-derive are called light-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. However, this should not be construed to mean that they occur in darkness or that they are not light-driven.

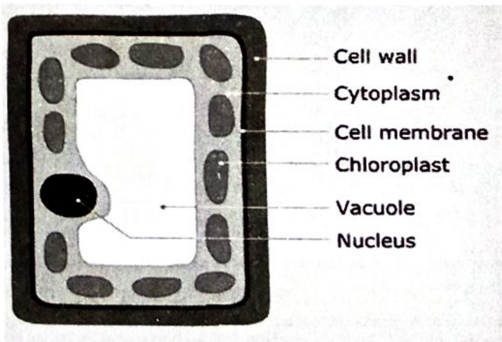
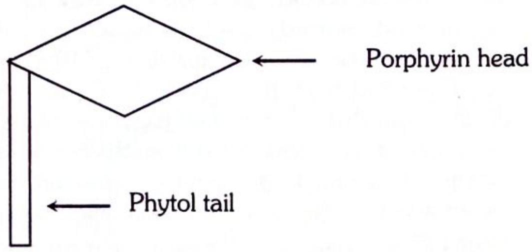


Fig. : Structure of Mesophyll Cells

- **Mesophyll Cells :** *Mesophyll cells* are a type of ground tissue found in the plant's leaves. There are two types of *mesophyll cells*: Palisade *mesophyll cells* and spongey *mesophyll cells.* The most important role of the *mesophyll cells* is in photosynthesis. It includes outer cell wall, cell membrane, cytoplasm, chloroplast, vacuole and nucleus.
- **Photosynthetic pigments** : Pigments are substances that have an ability to absorb light, at specific wavelengths. A chromatographic separation of the leaf pigments shows that the colour of leaves is due to four pigments:
  - Chlorophyll a - Bright or blue green in the chromatogram
  - Chlorophyll b - Yellow green
  - Xanthophylls - Yellow
  - Carotenoids - Yellow to yellow-orange

  Of these, chlorophyll a is the primary photosynthetic pigment.



- **Structure of Chlorophyll Pigments** : Chlorophyll has a tadpole like structure. It consists of a porphyrin head and a phytol tail. All chlorophylls have a complex ring structure chemically related to the porphyrin-like groups found in haemoglobin and cytochromes. It is the site of the electrons rearrangements when the chlorophyll is excited. It is a cyclic tetrapyrrolic structure with non-ionic magnesium atom.

Phytol tail is a long hydrocarbon tail is almost always attached to the ring structure. It anchors the chlorophyll to the hydrophobic portion of the thylakoids. Major types of chlorophylls include chlorophyll a, b, c, d, e; bacteriochlorophyll a and b etc.

Accessory pigments - All pigments other than chlorophyll a are called accessory pigments

- **Carotenoids :** Carotenoids are plant pigments responsible for bright red, yellow and orange hues in many fruits and vegetables. These pigments play an im portant role in plant health. Carotenoids are a class of phytonutrients ("plant chemicals") and are found in the cells of a wide variety of plants, algae and bacteria. They help plants absorb light energy for use in photosynthesis. They also have an important antioxidant function of deactivating free radicals – single oxygen atoms that can damage cells by reacting with other molecules. Carotenoids also act as antioxidants in the human body. They have strong cancer-fighting properties.
- **Xanthophylls :** Xanthophylls (phylloxanthins) are yellow pigments that occur widely in nature and form one of two major divisions of the carotenoid group; the other division is formed by the carotenes. They are present in egg yolk, algae, and petals of yellow flowers, among other sources. The xanthophylls include lutein, zeaxanthin, neoxanthin, violaxanthin, and cryptoxanthin, of which lutein is the primary ingested one.
- **Phycobilins :** Phycobilins are water-soluble pigments found in the stroma of chloroplast organelles that are present only in Cyanobacteria and Rhodophyta. The two classes of phycobilins include phycocyanin and phycoerythrin. Phycocyanin is a bluish pigment found in primarily cyanobacteria (blue-green algae) to aid in absorption of light in photosynthesis, while phycoerythrin is a pigment found in Rhodopyta (red algae) that is responsible for its characteristic red colour. It is an accessory pigment that allows red algae to carry out photosynthesis in deep water where wavelengths of blue light are most abundant by absorbing blue light and reflecting red light.

  These have two major roles in photosynthesis :

  a) They absorb light of different wavelengths and transfer the energy to chlorophyll molecules, thus they are also called antenna molecules. This enables a wider range of wavelength of incoming light to be utilised for photosynthesis.

  b) Carotenoids protect plant from excessive heat and prevent photo-oxidation (oxidative destruction by light) of chlorophyll pigments.

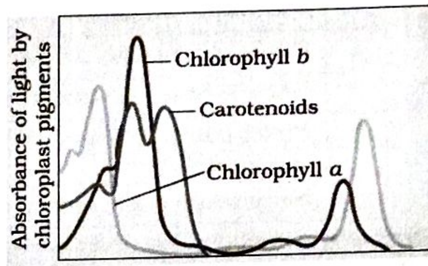
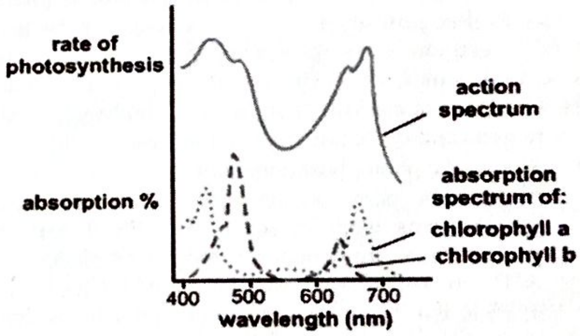


Fig. : Graph showing the absorption spectrum of chlorophyll a, b and the carotenoids

- **Absorption spectrum :** Let us study the graph showing ability of pigments to absorb lights of different wavelengths. The graphic curve showing the amount of energy of different wavelengths of light absorbed by substance/pigments.
- **Action spectrum :** The graphic curve showing the relative rates of photosynthesis at different wavelengths of light. Action spectrum of photosynthesis corresponds closely to absorption spectra of chlorophyll a showing that chlorophyll a is the chief pigment associated with photosynthesis.

Fig. : Graph showing action spectrum of photosynthesis



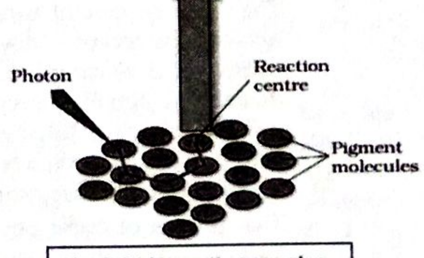
These graphs, together, show that most of the photosynthesis takes place in the blue and red regions of the spectrum, some photosynthesis does take place at the other wavelengths of the visible spectrum. These graph depict that maximum photosynthesis occurs at the wavelength at which there is maximum absorption by chlorophyll a i.e., in the blue and red regions. Both red and blue light are equally effective in photosynthesis but red light is more efficient.

6. Mechanism of Photosynthesis

- **Photochemical phase/Light Reaction**

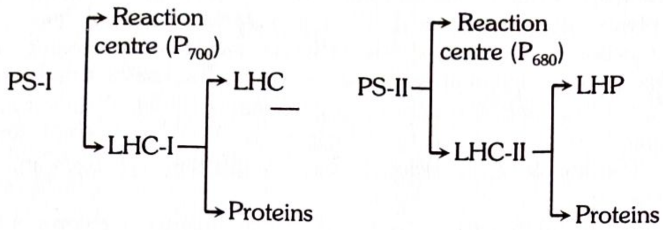
  Light reactions or the 'photochemical' phase is thought to be responsible for the formation of high-energy chemical intermediates, ATP and NADPH, and it includes light absorption, water splitting and release of oxygen. Several complexes are involved in this process which are discussed below :
- **Light absorbtion**

  These are group of pigments molecules which take part in the conversion of light energy into the chemical energy. The photosynthetic units are called photosystem I (PS – I) and Photosystem II (PS – II). Each unit has a reaction centre of a specific chlorophyll a molecule which absorbs light energy of long wavelength. These center can release electron upon absorption of energy. In PS-I, the reaction centre chlorophyll a has an absorption peak at 700 nm, hence is called P700, while in PS-II, reaction centre has an absorption maxima at 680 nm and is called P680.



The light harvesting complex

Reaction centre is surrounded by number of light harvesting pigment (LHP) molecules. These are also called antenna molecules. These absorb photons of different wavelength and transfer this energy to reaction centre. Harvesting molecules occur in form of specific complexes called light-harvesting complexes (LHC) called LHC-I and LHC-II. The pigment molecules of these complexes are bound to proteins. These help to make photosynthesis more efficient.



Some of the important differences between the two photosystems are :

	Photosystem I / Pigment system I	Photosystem II / Pigment system II
1.	The reaction centre is P_{700}	The reaction centre is P_{680}
2.	PS I lies on the outer surface of the thylakoids	PS II occurs on the inner surface of the thylakoids
3.	Found in both grana and stroma lamellae	Found in grana lamellae only
4.	Participates in both cyclic as well as non-cyclic flow of electrons	It is involved only in non-cyclic flow of electrons
5.	Non associated with splitting of water	Associated with splitting of water and release of O_2

- **Splitting of water :** The electrons that were removed from PS II must be replaced. This is achieved by electrons available due to splitting of water. 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. Water is split into H^+, [O] and electrons. The protons and oxygen formed by splitting of water is released within the lumen of the thlakoids. The oxygen produced is released as one of the net products of photosynthesis.
- **Formation of High energy Chemical Intermiadiate :** Arnon used the term assimilatory powers to refer ATP and NADPH. The process of reduction of NADP into NADPH + H^+ may be denoted as electron transport system (ETS) in photosynthesis while the process of formation of ATP from ADP and inorganic phosphate (ip) utilising light energy is called photophosphorylation. The flow of electrons through ETS is linked to photophosphorylation.

Electron transport chain is a series of electron carriers over which electrons pass in a downhill journey releasing energy at every step that is used in generating an electrochemical proton gradient which helps in synthesising ATP.

Note : **Redox potential :** It is the measure of the tendency of a chemical species to acquire electrons and thereby be reduced. Also, called oxidation-reduction potential, it is measured in volts (*V*) or milli volts (*mV*).

Based on path of electron, associated photophosphorylation can be identified as non-cyclic and cyclic photophosphorylation.

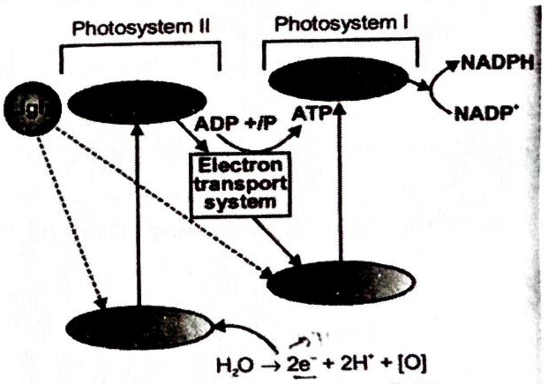


Fig. : Z scheme of light reaction

a) Non-cyclic photophosphorylation

It involves both photosystem I and photosystem II. These two photosystems work in series, first PS II and then PS I. The two photosystems are connected through an electron transport chain. Both ATP and NADPH+H^+ are synthesised by this kind of electron flow. First in PS II, the P_{680} nm wavelength of red light causing electrons to become excited and jump into an orbit which is farther from the atomic nucleus.

These electrons are picked up by an electron acceptor which passes them to an electron transport system of cytochromes. This movement of electrons is downhill on redox potential scale. The electrons are then passed onto the pigments of PS I, without being used as they pass through the electron transport chain.

Simultaneously, electrons in the reaction center of PS I (P_{700}) are excited when they receive light of wavelength 700 nm and these electrons are transferred to an other acceptor molecule that has a greater redox potential. These electrons are then moved downhill again to a molecule of NADP$^+$. The addition of these electrons reduces the NADP$^+$ to NADPH+H^+.

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

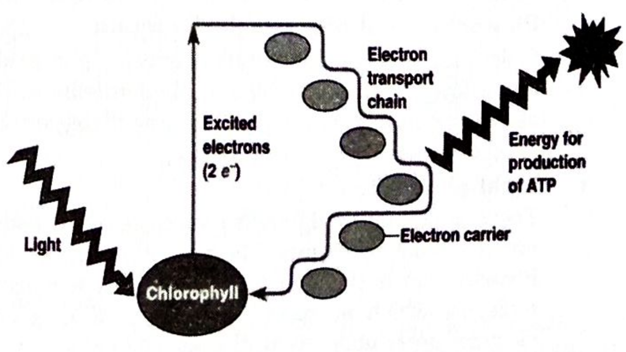


Fig. : Cyclic Phosphorylation

b) Cyclic photophosphorylation

The process of cyclic photophosphorylation involves only PS I and this process takes place in the stroma lamellae membrane. When only PS I is functional the electron is circulated within the photosystem and the phosphorylation occurs, due to cyclic flow of electrons. The membrane or lamellae of the grana have both PS I and PS II, the stroma lamella membranes lack PS II as well as NADP reductase enzyme. The excited electron does not pass on to $NADP^+$ and is cycled back to the PS I complex through the electron transport chain. Cyclic photophosphorylation also occurs when only light of wavelength beyond 680 nm are available for excitation.

Some important differences between cyclic and non-cyclic photophosphorylation are as follows:

	Cyclic photophosphorylation	Non-cylic photophosphorylation
1.	It is performed by photosystem I independently.	It is performed by collaboration of both photosystems II and I.
2.	An external source of electrons is not required.	The process requires an external electron donor.
3.	It is not connected with photolysis of water. Therefore, no oxygen is evolved.	It is connected with photolysis of water and liberation of oxygen occurs.
4.	It synthesizes ATP only.	It is not only connected with ATP synthesis, but also with production of NADPH.
5.	It operates under low light intensity, anaerobic conditions or when CO_2 availability is poor.	Non-cyclic photophosphorylation takes place under optimum light, aerobic conditions and in the presence of carbon dioxide.
6.	The system does not take part in photosynthesis except in certain bacteria.	The system is connected with CO_2 fixation in green plants.
7.	It occurs mostly in stroma lamellae membrane.	It occurs in the granal thylakoids.

Chemiosmotic hypothesis

Chemiosmotic hypothesis was explained by P. Mitchell. This mechanism explains how ATP is synthesised in the chloroplast. ATP synthesis is linked to the development of a proton gradient across the membrane of the thylakoid and the proton accumulation is towards the inside of the membrane i.e., in the lumen.

There are several processes that take place during activation of electrons and their transport which lead to the development of a proton gradient.

(a) Photolysis of water towards thylakoid lumen : The splitting of the water molecule takes place on the inner side of the membrane and so the hydrogen ions (protons) that are produced, they accumulate within the lumen of the thylakoids.

(b) Transfer of H^+ from stroma to lumen as electrons move through photosystems : The primary acceptor of electron located towards the outer side of the membrane transfer its electron to an H^+ carrier, and this molecule then removes a proton from the stroma while transporting an electron. When this H^+ carrier molecule passes on its electron to an electron carrier present on the inner side of the membrane, the H^+ is released into the lumen of the membrane.

(c) NADPH reductase reaction occur towards stroma : The NADP reductase enzyme is located on the stroma side of the membrane. Protons are necessary for the reduction of $NADP^+$ to $NADPH+H^+$ and these protons are removed from the stroma. So, within the chloroplast, protons in the stroma decrease in number, while in the lumen there is accumulation of protons. This causes increase in pH in the lumen and creates a proton gradient across the thylakoid membrane.

This gradient is important because the breakdown of this gradient leads to release of energy. The gradient is broken down due to the movement of protons across the membrane to the stroma through the transmembrane channel of the F_0 is embedded in the membrane and forms a transmembrane channel that carries out facilitated diffusion of protons across the membrane.

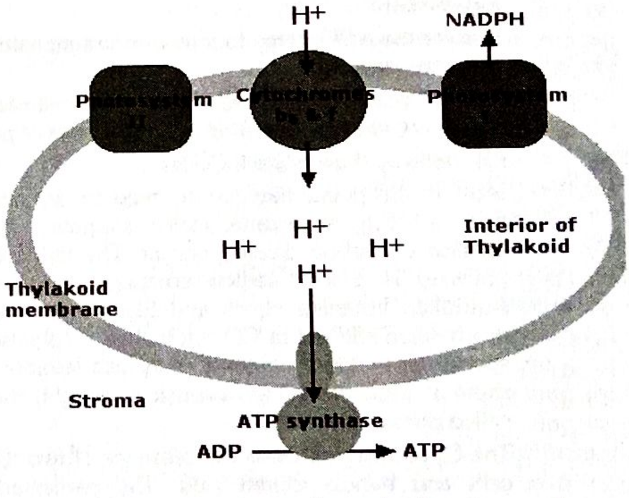


Fig. : ATP synthesis through chemiosmosis

The other portion is called F_1 and protrudes on the outer surface of the thylakoid membrane on the side that faces the stroma. The breakdown of this gradient provides enough energy to cause a conformational change in the F_1 part of the ATPase, which makes the enzyme synthesise several molecules of ATP.

Chemiosmosis process requires a membrane, a proton pump, a proton gradient and ATPase enzyme. Energy is used to pump protons across the membrane into the lumen, which creates a proton gradient across the membrane. ATPase enzyme has transmembrane channel that allows diffusion of protons back across the membrane, this releases energy to activate ATPase enzyme which catalyse the formation of ATP. Along with the NADPH produced, the ATP is used in the biosynthetic reaction taking place in the stroma, responsible for the fixation of carbon dioxide and synthesis of sugars.

- **Biosynthetic Phase/Dark Reaction**
  The products of light reaction i.e., ATP and NADPH are essential for assimilation of CO_2 to carbohydrates. This is the biosynthetic phase of photosynthesis. These reactions take place in the stroma of chloroplast where all the enzymes required are present. This process does not depend directly on the presence of light but is dependent on the products of light reaction i.e., ATP and NADPH. This could also be verified as immediately after light becomes unavailable, this biosynthetic process continues for some time and then stops. But, if then, light is made available again, the synthesis starts again. Hence, calling the biosynthetic phase as the dark reaction is a misnomer. The dark reaction occurs through Calvin cycle. May be supported by C_4 cycle or Crassulacean Acid Metabolism (CAM) in certain plants.

- **C3 Pathway (Calvin Cycle)**
  Melvin Calvin used radioactive ^{14}C in algal photosynthesis studies. This led to the discovery that the first CO_2 fixation product was a three-carbon organic acid. He also helped to mark out the complete biosynthetic pathway, hence it is called Calvin cycle. The first stable product identified was 3-phosphoglyceric acid (PGA), hence it is named C_3 pathway. Calvin cycle occurs in all photosynthetic plants whether they have C_3 or C_4 pathway.

Primary acceptor of CO_2

The primary acceptor molecule during the C_3 cycle is a five carbon ketose sugar-Ribulose bisphosphate (RuBP). The enzyme for CO_2 fixation is RuBisCO (Ribulose Bisphosphate Carboxylase Oxygenase). It is the most abundant enzyme on earth. It is characterised by the fact that its active site can bind to both CO_2 and O_2, hence the name. RuBisCO has a much greater affinity for CO_2 than for O_2 and the binding is competitive. It is the relative concentration of O_2 and CO_2 that determines which of the two will bind to the enzyme. Before the scientists discovered the 5-carbon ketose sugar as primary acceptor it was believed that since the first product was a C_3 acid, the primary acceptor would be a 2-carbon compound.

Stages of Calvin cycle

Calvin cycle can be described under three stages

(a) **Carboxylation :** It is the fixation of CO_2 into a stable organic intermediate. In this, CO_2 is utilised for the carboxylation of RuBP. This reaction is catalysed by the enzyme RuBis CO and it results in the formation of two molecules of 3-PGA (3-phosphoglyceric acid).

(b) **Reduction :** These reaction lead to the formation of glucose. The steps involve utilization of two molecules of ATP for phosphorylation and two of NADPH for reduction, per molecule of CO_2 fixed. The fixation of six molecules of CO_2 and six turns of the cycle are required for the removal of one molecule of glucose from the pathway.

(c) **Regeneration :** For the cycle to continue uninterrupted, regeneration of the CO_2 acceptor molecule is crucial. This step requires one ATP for phosphorylation to form RuBP. To make one molecule of glucose six turns of the cycle are required 18 ATP and 12 NADPH molecules are used to make a molecule of glucose.

For every CO_2 molecule entering Calvin cycle, three molecules of ATP and two molecules of NADPH are required. It is to meet this difference in number of ATP and NADPH that the cyclic phosphorylation takes place.

Significance of Calvin Cycle

- It is the main biochemical pathway during the dark reaction(Phase -II) of photosynthesis, results in the synthesis of carbohydrates from CO2 (assimilation of carbon).
- It depends on the light reaction (Phase-I) for the supply of the assimilatory power (ATP and $NADPH_2$) required for carbon assimilation.
- It stores the ATP energy formed during light reaction in the carbohydrate molecules as the food energy also act as food energy for all the organisms
- Calvin Cycle (C-3 cycle) reaction occur in all photosynthetic plants i.e. C-3, C-4 and CAM plants, during the dark phase of photosynthesis.
- C4 Pathway (Hatch-Slack Cycle)
  Most of the plants that are adapted to dry tropical regions have the C_4 pathway. E.g., sugarcane, maize, sorghum etc. In these plants, double fixation of carbon dioxide occurs. The initial or the first product of this pathway is a four carbon compound-Oxaloacetic acid (OAA). Two Australian botanists Hatch and Slack discovered that tropical plants are much more efficient in CO_2 utilization. C_4 plants are special as they have a special type of leaf anatomy, they can tolerate higher temperatures, they show a response to high intensities of light, they lack a wasteful process called photorespiration,
  The C_4 pathway requires the presence of two types of cells i.e., mesophyll cells and bundle sheath cells. The particularly large cells around the vascular bundles of C_4 plants are called bundle sheath cells, these cells may form several layers around the vascular bundles, they are characterised by having large number of special anatomy of leaves of the C_4 plants is called 'Kranz anatomy' 'Kranz means wreath and is a reflection of the arrangement of cells.
- Process of hatch-slack pathway It is a cyclic process. The primary CO_2 acceptor is a three-carbon molecule phosphoenol pyruvate (PEP) and it is present in mesophyll cells. The enzyme that catalyses this CO_2 fixation is PEP carboxylase or PEPcase. The mesophyll cells of C_4 plants lack the enzyme RuBisCO.
  The 4-carbon oxaloacetic acid (OAA) is formed in the mesophyll cells. It is then converted to other four carbon compounds like malic acid or aspartic acid in the mesophyll cells itself, these are then transported to the bundle sheath cells. In the bundle sheath cells, these C_4 acids are broken down to release CO_2 and a three-carbon molecule. The CO_2 released in the bundle sheath cells enters the C_3 or the Calvin pathway. The bundle sheath cells are rich in an enzyme RuBisCO but lacks PEPcase. The three molecule is transported back to the mesophyll cells where it is converted to PEP again, thus completing the cycle.

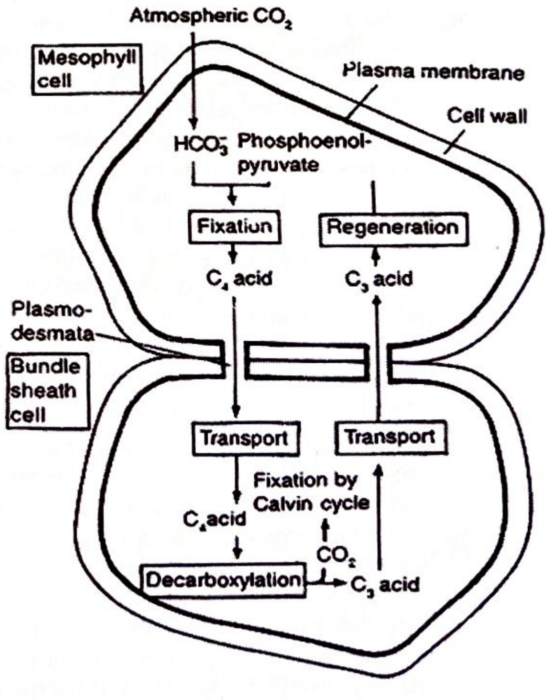


Fig. : Diagrammatic representation of the hatch and slack pathway

- **Importance of C_4 plants**
They can tolerate saline conditions due to abundant occurrence of organic acids (malic and oxaloacetic acid) in them which lowers their water potential than that of soil. Can perform photosynthesis even when their stomata are closed due to the presence of strong CO_2 fixing enzyme i.e., PEPcase. Concentric arrangement of cells in leaf produces smaller area in relation to volume for better water utilization.
Regeneration of PEP from C3 acid requires 2 ATP equivalent. However, there is no net gain or loss of NADPH in C4 cycle.
ATP consumed in C_4 plants :
C_4 cycle- 2 ATP per CO_2 fixed
C_3 cycle- 3 ATP per CO_2 fixed
Total = 5 ATP per CO_2 fixed
Thus, to form a hexose or to fix 6 CO_2, 6 × 5 ATP = 30 ATP are consumed.

Some major differences between C_3 pathway and C_4 pathway are :

C_3 pathway	C_4 pathway
The primary acceptor of CO_2 is RuBP – a six carbon compound.	The primary acceptor of CO_2 is PEP – a three carbon compound.
The first stable product is 3-phosphoglycerate.	The first stable product is oxaloacetic acid.
It occurs in the mesophyll cells of the leaves.	It occurs in the mesophyll and bundle-sheath cells of the leaves.
It is a slower process of carbon-fixation.	It is a faster process of carbon fixation.
3ATP are consumed to fix one CO_2.	2ATP are consumed to fix one CO_2.

- **CAM (Crassulacean Acid Metabolism) Pathway :** Certain plants called CAM plants (with Crassulacean Acid Metabolism – CAM) have scotoactive stomata. These plants fix CO_2 during night but form sugars only during day (when RuBisCO is active), e.g., Sedum, Kalanchoe, Pineapple, Opuntia.

7. Factor Affecting Photosynthesis

The rate of photosynthesis is very important in determining the yield of the plants including crop plants. An understanding of the factors that affects photosynthesis is very necessary. Photosynthesis is under the influence of both internal (plant) and external factors.

- **plant factors** include the number, size, age and orientation of leaves, mesophyll cells and chloroplasts, internal CO_2 concentration and amount of chlorophyll. The plant factors are dependent on the genetic predisposition and the growth of the plant.
- **external factors** include the availability of sunlight, temperature, CO_2 concentration and water. Though several factors interact and simultaneously affect photosynthesis rate, at any point the rate is determined by the factors available at sub-optimal levels.

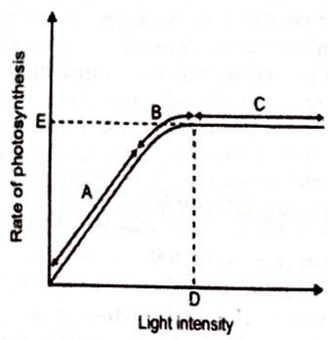


Fig. : Graph of light intensity on the rate of photosynthesis

a) **Light**

1. **Light intensity :** There is a linear relationship between incident light and CO_2 fixation at low light intensities. At higher light intensities, gradually the rate does not show further increase as other factors become limiting. The light saturation occurs at 10 percent of the total sunlight available to plants. Increase in incident light beyond a point causes the breakdown of chlorophyll and thus resulting in decrease in photosynthesis. Hence, except for plants in shade or in dense forests, light rarely becomes a limiting factor.
2. **Light quality :** Light between 400-700 nm wavelength constitute the photosynthetically active radiation (PAR). Maximum photosynthesis takes place in red and blue light of the visible spectrum and minimum photosynthesis takes place in green light.
3. **Duration of light :** Light duration does not affect the rate of photosynthesis, but it affects the overall photosynthesis.

b) **Carbon Dioxide Concentration -** It is a major limiting factor influencing the rate of photosynthesis. The concentration of CO_2 is very low in the atmosphere (between 0.03 percent and 0.04 percent).This level of carbon dioxide is far below the requirement for optimum photosynthesis. Increase in concentration up to 0.05 percent can cause an increase in the rate of photosynthesis but beyond this level, it becomes damaging over longer periods

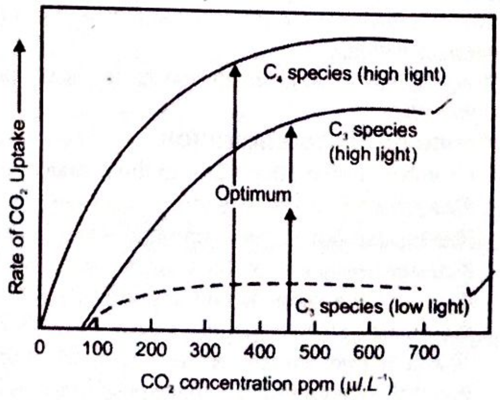


Fig. : Photosynthetic response of C_3 and C_4 plants to CO_2 concentration

c) The C_3 and C_4 plants respond differently to CO_2 concentration. At low light intensities neither type responds to high CO_2 concentration. At high light intensities, both C_3 and C_4 plants show increase in the rate of photosynthesis. The C_4 plants show saturation at about 360 μ/L^{-1} (ppm), while C_3 plants show saturation only beyond 450 μ/L^{-1} (ppm), thus, the current concentration of CO_2 is limiting for C_3 plants. As C_3 plants respond to higher CO_2 concentration by showing increased rate of photosynthesis, leading to higher productivity, this has been used for the production of greenhouse crops like tomatoes and bell pepper. These crops are allowed to grow in CO_2 enriched atmosphere that leads to higher yields.

d) **Temperature -** Photosynthesis can take place over a wide range of temperature. The light reactions are temperature sensitive but they are affected to a much lesser extent. The dark reactions being enzymatic are temperature controlled. Again, the temperature optimum for photosynthesis of different plants also depends on the habitat that they are adapted to. Tropical plants have a higher temperature optimum than the plants adapted to temperate climates.The C_4 plants respond to higher temperatures and they show higher rate of photosynthesis, while C_3 plants have much lower temperature optimum. Optimum temperature in C_3 plant in 20-25°C and C_4 plant is 35°-45°. The minimum temperature at which most plants starts photosynthesis is 0-5°C. It is as low as -35°C for gymnosperms. Maximum temperature at which photosynthesis can occur is 50-55°C for desert plants and 70-75° for hot spring algae.

Water - Water is one of the raw materials utilized for the process of photosynthesis. Photosynthetic process utilizes less than 1% of the water absorbed by a plant, hence it is rarely a limiting factor in photosynthesis. Water stress causes the stomata to close, hence reducing the CO_2 availability as gaseous exchange could not occur. Also, water stress makes leaves wilt, thus reducing the surface area of the leaves and the metabolic activity reduces as well. Thus, the effect of water as a factor is more through its effect on the plant, rather than directly on photosynthesis.

- **Law of limiting factors -** In 1905, Blackman gave the law of limiting factors. When several factors affect any biochemical process, then this law comes into effect. This states that :If a chemical process is affected by more than one factor then its rate will be determined by the factor which is nearest to its minimal value. It is the factor which directly affects the process if its quantity is changed.To illustrate the law, suppose light intensity supplied to a leaf is just sufficient to utilize 5 *mg* of CO_2 per hour in photosynthesis. As the CO_2 does not have any affect upon the rate. Light has now become the limiting factor and further increase in rate of photosynthesis will occur only by increasing the intensity of light.
- Oxygenic photosynthesis : In green plants and cyanobacteria water is used as a source of reducing power. Photolysis of water results in release of oxygen as by-product. This photosynthesis which involves oxygen release is called oxygenic photosynthesis.
- Anoxygenic photosynthesis : In bacteria evolution of oxygen during photosynthesis has not been demonstrated as they are incapable of using H2O as reducing power. Instead it is obtained from H2S thiosulphate etc.
- Significance of Photosynthesis
  Photosynthesis is the only process which produces enormous quantities of organic matter for sustaining the life on this globe. It is the only known method of manufacturing organic food from inorganic raw materials. Animals including man are directly or indirectly dependent on photosynthetic plants for their food. All flesh is grass. Photosynthetic products not only build up the bodies of organisms but also provide energy for carrying out metabolic activities and different types of movements. The chemical energy present in the organic food is the converted form of radiant or solar energy. All life is bottled sunshine. Coal, petroleum and natural gas represent the photosynthetic capital of the past geological ages. They have been formed by the application of heat and compression over the plant and animal bodies in the deeper layers of earth. Along with wood they provide a sufficient portion of energy required for domestic, industrial and transport needs.
  Several materials derived from the organic world (and hence photosynthesis) are in our daily use. Examples: Natural fibres, drugs, vitamins, gums, tannins, turpentine, furniture, etc. Oxygen is being constantly consumed and carbon dioxide evolved by the respiration of animals and plants and by the burning of wood, coal, petroleum or natural gas. High carbon dioxide content of the atmosphere is toxic. Lower concentrations of oxygen are equally harmful. Luckily, green plants keep the concentration of the two gases almost constant by absorbing carbon dioxide and evolving oxygen during photosynthesis.

8. Photorespiration

Photorespiration is a process which involves loss of fixed carbon as CO_2 in plants in the presence of light it is initiated in chloroplasts. This process does not produce ATP or NADPH and is a wasteful process.
Photorespiration occurs usually when there is high concentration of oxygen. Under such circumstances. RuBisCO, the enzyme that catalyses the carboxylation of RuBP during the first step of Calvin cycle, functions as an oxygenase. Some O_2 does bind to RuBisCO and hence CO_2 fixation is decreased. The RuBP binds with O_2 to form one molecule of PGA (3C compound) and phosphoglycolate (2C compound) in the pathway of photorespiration.
There is neither the synthesis of sugar, nor of ATP. Rather, it results in the release of CO_2 with the utilization of ATP. It leads to a 25 percent loss of the fixed CO_2. O_2 is first utilized in chloroplast and then in peroxisomes. Photorespiration or C_2 cycle involves three organelles viz., chloroplast, peroxisomes and mitochondria. Loss of CO_2 occurs in mitochondria.
In C_4 plants, photorespiration does not occur. This is because these plants have a mechanism that increases the concentration of CO_2 at the enzyme site. During the C_4 pathway, when the C_4 acid from the mesophyll cells is broken down in the bundle sheath cells, it releases CO_2 – this results in increasing the intracellular concentration of CO_2. This is turn, ensures that the RuBisCO functions as a carboxylase minimising the oxygenase activity.
Thus, the productivity and yields are better in C_4 plants as compared to C_3 plants. In addition, the C_4 plants show tolerance to higher temperature also.

Importance of Photorespiration

- Photorespiration takes place in the presence of light under high temperature and oxygen concentration.
- As a result of photorespiration excess amount of carbon dioxide is evolved.
- Photorespiration always competes with the carbon fixing process.
- It causes heavy loss of fixed carbon and does not produce any energy rich compounds.
- It protects the plants from the photo oxidative damage. When the amount of carbon dioxide is low so as to utilize the light energy, the excess light energy is then used for photorespiration.
- The increased amount of carbon dioxide favours photosynthesis whereas the increased amount of oxygen and light energy initiates the photorespiration. The photorespiration is negligible or absent in the C_4 plants.

Important -
Photorespiration is not related to aerobic respiration as aerobic respiration occurs throughout the day and night in all types of cells, but photorespiration occurs in presence of light in green cells only. ATP is produced in aerobic respiration unlike photorespiration where ATP is consumed.

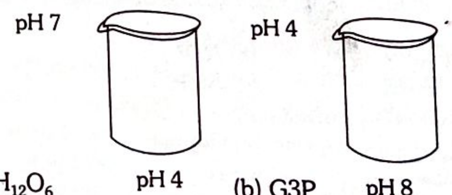
13. Photosynthesis In Higher Plants – Multiple Choice Questions

1. History of photosynthesis

1. Which of the following technique was used by Calvin in determining carbon pathway
(a) Autoradiography (b) Electrophoresis
(c) Spectrophotometry (d) Histochemistry
2. Two pigment system theory of photosynthesis was proposed by or Concept of evidence for the existence of two photosystems in photosynthesis was given by
(a) Hill (b) Blackman
(c) Emerson (d) Arnon
3. Who received the Nobel Prize for working out the early carbon pathway of photosynthesiss
(a) Calvin (b) Krebs
(c) Khorana (d) Watson
4. The law of limiting factor for photosynthesis was enunciated by
(a) Blackman (b) Hill
(c) Ruben (d) Kalmen
5. Most of the plants contain a green colouring pigment which is responsible for photosynthesis. This pigment was named chlorophyll by
(a) Melvin Calvin (b) Jean Senebier
(c) Julius Robert Mayer (d) Pelletier Caventou
6. The process of photophosphorylation was discovered by
(a) Calvin (b) Arnon
(c) Priestley (d) Warburg
7. The significance of light and chlorophyll in photosynthesis was discovered by
(a) Priestley (b) Ingenhousz
(c) Englemann (d) Blackman
8. 'Thylakoid' name was given by
(a) Arnon (b) Park and Biggins
(c) Park and Fortran (d) Menke
9. The scientist, who proved that bacteria use H_2S gas and CO_2 to synthesize carbohydrate, is
(a) Van Niel (b) Ruben
(c) Jean Senebier (d) Julius Robert Mayer
10. Who proposed the CAM pathway of CO_2 fixation
(a) Benson and associates (b) Rouhani and associates
(c) Hatch and associates (d) Arnon and associates

2. Experiments

1. Two plants A and B are supplied with CO_2 with H_2O^{18} and CO_2^{18} with H_2O respectively which of the following plant releases O18 type oxygen in photosynthesis
(a) A plant (b) B plant
(c) Both (a) and (b) (d) First (a) and then (b)
2. Engelmann's experiment with Spirogyra demonstrated that
(a) The full spectrum of sunlight is needed for photosynthesis
(b) Only red wavelengths are effective in causing photosynthesis
(c) Only blue wavelengths are effective
(d) Both blue and red wavelengths are effective
3. Path of carbon in photosynthesis was found by using
(a) Centrifugation (b) Radioisotopes
(c) Fractionation (d) Chromatography
4. The first experiment on photosynthesis in flashing light was carried out by
(a) F. F. Blackman
(b) Robert Emerson and Arnold
(c) Melvin Calvin
(d) Robert Hill
5. The path of CO_2 in the dark reaction of photosynthesis was successfully traced by the use of the following or The dark reaction is traced by
(a) O_2^{18} (b) $C^{14}O_2$
(c) P^{36} (d) X–rays
6. Algae used by Calvin and associates for photosynthetic research is
(a) Chlorella (b) Chlamydomonas
(c) Volvox (d) All the above
7. What plant is used in an experiment commonly performed in the laboratory to demonstrate the evolution of oxygen in photosynthesis
(a) Sunflower (b) Hydrilla
(c) Croton (d) Balsam
8. Moll's experiment shows
(a) Unequal transpiration from two surfaces of the leaf
(b) The relation between transpiration and absorption
(c) CO_2 is required for photosynthesis
(d) Chlorophyll is essential for photosynthesis
9. Persons who received Nobel Prizes for their work with green plants are
(a) Calvin and Watson (b) Calvin and Borlang
(c) Beadle and Tatum (d) Flemming and Waksman
10. The given diagram represents an experiment with isolated chloroplasts. The chloroplasts were first made acidic by soaking them in a solution at pH 4. After the thylakoid space reached pH 4, the chloroplast was transferred to a basic solution at pH 8. The chloroplasts are then placed in the dark. Which of these compounds would you expect to be produced



(a) $C_6H_{12}O_6$ (b) G3P
(c) NAD (d) ATP
11. Which is the evidence to show that O_2 is released during photosynthesis comes from water
(a) Isotopic O_2 supplied as H_2O appears in the O_2 released in photosynthesis
(b) Isolated chloroplast in water releases O_2 if supplied potassium ferrocyanide or some other reducing agent
(c) Photosynthetic bacteria use H_2S and CO_2 to make carbohydrates
(d) All the above

3. Photosynthetic apparatus

1. The first event in photosynthesis is
(a) Synthesis of ATP
(b) Photoexcitation of chlorophyll and ejection of an electron
(c) Photolysis of water
(d) Release of oxygen
2. Solar energy is converted into ATP in
(a) Mitochondria (b) Chloroplasts
(c) Ribosomes (d) Peroxisomes

3. The plants growing in dark show yellowing in leaves and elongated internodes, this condition is called as
(a) Etiolation (b) Chlorosis
(c) Dechlorosis (d) Dark effect

4. Which of the following equation can be more appropriate for photosynthesis
(a) $6CO_2 + 6H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} C_2H_{12}O_6 + 6O_2$
(b) $6CO_2 + 12H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} C_6H_{12}O_6 + 6H_2O + 6O_2$
(c) $12CO_2 + 6H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} 2C_6H_{12}O_6 + 6O_2$
(d) None of the above

5. Emerson effect explain the phenomenon of
(a) Transpiration
(b) Absorption of water by roots
(c) Photosynthesis
(d) Respiration

6. The percentage of light energy utilized for photosynthesis by higher plants is
(a) 100% (b) 50 %
(c) 10% (d) 1 to 2%

7. During photosynthesis
(a) Both CO_2 and water get oxidized
(b) Both CO_2 and water get reduced
(c) Water is reduced and CO_2 is oxidized
(d) Carbon dioxide gets reduced and water get oxidised

8. Assimilatory power refers to
(a) Generation of ATP and $NADPH_2$
(b) Reduction of CO_2
(c) Splitting of water
(d) Disintegration of plastids

9. Photosynthesis is a
(a) Exothermic process (b) Exergonic process
(c) Anabolic process (d) Catabolic process

10. For photosynthesis (*i.e.* for the synthesis of organic matter), the green plants need only
(a) Light (b) Chlorophyll
(c) CO_2 and water (d) All of these

11. Which one of the following is the energy currency of the cell or The common immediate source of energy in cellular activity is
(a) Phosphate (b) ATP
(c) ADP (d) AMP

12. Which metal ion is a constituent of chlorophyll
(a) Iron (b) Copper
(c) Magnesium (d) Zinc

13. Chemosynthetic bacteria obtain energy from
(a) Sun (b) Infrared rays
(c) Organic substance (d) Inorganic chemicals

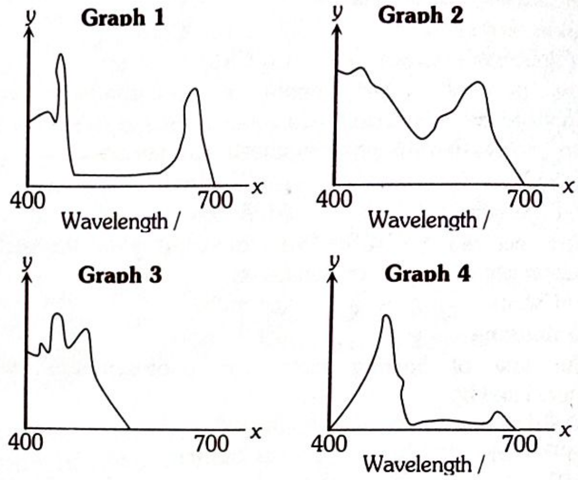
14. During light reaction in photosynthesis, the following are formed
(a) ATP and sugar
(b) Hydrogen, O_2 and sugar
(c) ATP, hydrogen donor and O_2
(d) ATP, hydrogen and O_2 donor

15. Photosynthesis is
(a) Oxidative, exergonic, catabolic
(b) Reductive, endergonic, anabolic
(c) Reductive, exergonic, anabolic
(d) Reductive, endergonic, catabolic

16. Chlorophyll '*a*' is found in
(a) All oxygen releasing photosynthetic forms
(b) All plants except fungi
(c) All higher plants that photosynthesize
(d) All photosynthetic prokaryotes and eukaryotes

17. The empirical formula for chlorophyll '*a*' is
(a) $C_{35}H_{72}O_5N_4Mg$ (b) $C_{55}H_{70}O_6N_4Mg$
(c) $C_{55}H_{72}O_5N_4Mg$ (d) $C_{54}H_{70}O_6N_4Mg$

18. Three of the graphs below show the absorption spectra of photosynthetic pigments. One graph shows the action spectrum of photosynthesis for a plant containing the pigments.
The entire x-axis show wavelength. Three of the y-axis show light absorption. One y-axis shows the rate of photosynthesis



	Chlorophyl l a	Absorption Chlorophyll b	Spectra Carotenoi ds	Action spectru m
(a)	3	2	4	1
(b)	2	4	3	1
(c)	2	1	3	4
(d)	1	4	3	2

19. The process in which excess energy is lost by light waves is called
(a) Fluorescence (b) Photophosphorylation
(c) Photolysis (d) Photooxidation

20. A pigment which absorbs red and far-red light is
(a) Phytochrome (b) Carotene
(c) Cytochrome (d) Xanthophyll

21. Which pigment is absent in chloroplast

Or

Which one of the following does not play any role in photosynthesis
(a) Xanthophyll (b) Anthocyanin
(c) Chlorophyll '*a*' (d) Carotene

22. Match the following and choose the correct combination from the options given

	Column – I		Column – II
A.	Visible light	1.	0.1 to 1 *nm*
B.	Ultraviolet	2.	400 to 700 *nm*
C.	X-Rays	3.	Longer than 740 *nm*
D.	Infrared	4.	100 to 400 *nm*
		5.	< 0.1 *nm*

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

23. Quantasomes are found in
(a) Surface of cristae
(b) The surface of the plasma membrane
(c) The surface of the nuclear membrane
(d) Surface of thylakoids

24. Suspension of isolated thylakoids in culture medium containing CO_2 and H_2O does not produce hexose due to the absence of which of the following

(a) ATP (b) Enzyme
(c) Proteins (d) Hill reagent

25. Match the sites in column I with the processes in column II and choose the correct combination from the options

	Column I		Column II
A.	Grana of chloroplast	1.	Kreb's cycle
B.	Stroma of chloroplast	2.	Light reaction
C.	Cytoplasm	3.	Dark reaction
D.	Mitochondrial matrix	4.	Glycolysis

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

26. The synthesis of ATP in photosynthesis and respiration is essentially an oxidation-reduction process involving the removal of energy from

(a) Oxygen (b) Phytochrome
(c) Cytochrome (d) Electrons

27. Chemosynthesis and photosynthesis are alike in that both

(a) Are associated with heterotroph
(b) Require sunlight as an energy source
(c) Methods of autotrophic nutrition
(d) Occur in tracheophytes

28. A phenomenon which converts light energy into chemical energy is

(a) Respiration (b) Photosynthesis
(c) Transpiration (d) None of these

29. Light energy is converted into chemical energy in the presence of

(a) Pyrenoids (b) Chloroplasts
(c) Ribosomes (d) Mesosomes

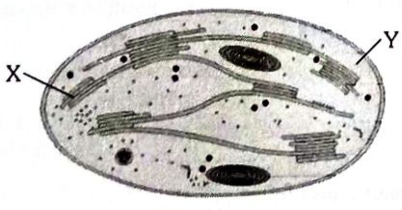
30. In the overall process of photosynthesis, the number of CO_2, water, sugar and O_2 molecules utilized and produced is

(a) 12 (b) 13
(c) 19 (d) 31

31. ATP synthesis during photosynthesis is termed as

(a) Photophosphorylation (b) Oxidative phosphorylation
(c) Lederberg (d) Watson and Crick

32. See the following diagram and identify X and Y with their functions



	X		Y	
	Structure	Function	Structure	Function
(a)	Grana	CO_2 fixation	Lamellae	Photolysis of water
(b)	Stroma	Photolysis	Grana	CO_2 fixation
(c)	Grana	CO_2 fixation	Stroma	Photolysis of water
(d)	Grana	Photolysis of water	Stroma	CO_2 fixation

33. The maximum evolution of oxygen is by the greatest producers of organic matter

(a) Great land area (b) Crops
(c) Phytoplankton of sea (d) Forests

34. Chlorophyll '*a*' molecule at its carbon atom 3 of the pyrrole ring II has one of the following

(a) Aldehyde group (b) Methyl group
(c) Carboxylic group (d) Magnesium

35. Energy transfer in photosynthesis occurs as

(a) Phycoerythrin → Phycocyanin → Carotenoid → Chlorophyll a
(b) Chlorophyll *b* → Carotenoid → Phycoerythrin → Chlorophyll a
(c) Phycocyanin → Phycoerythrin → Carotenoid → Chlorophyll-a
(d) Chlorophyll → Carotenoid → Phycocyanin → Chlorophyll a

36. Which of the following crop plant is a very efficient converter of solar energy and whose net productive value ranges from 2 *kg* to 4 *kg/m*^{2} or even higher

(a) Sugarcane (b) Rice
(c) Wheat (d) Bajra

4. Light reaction/Pigments

1. Which of the following pigment is yellow in colour

(a) Chlorophyll '*a*' (b) Chlorophyll '*b*'
(c) Carotene (d) Xanthophyll

2. Number of thylakoids in a granum is

(a) 5-10 (b) 2-100
(c) 100-150 (d) 150-200

3. Consider the following statements regarding photosynthesis find the correct options

(A) ATP formation during photosynthesis is termed as photophosphorylation
(B) Kranz anatomy pertains to leaf
(C) Reduction of $NADP^+$ to $NADPH$ occurs during Calvin cycle
(D) In a chlorophyll molecule magnesium is present in phyto tail

(a) (A) and (B) are correct (b) (C) and (D) are correct
(c) (A) and (C) are correct (d) (A) and (D) are correct
(e) (B) and (C) are correct

4. Manganese and Chlorine is required in

(a) Nucleic acid synthesis
(b) Plant cell wall formation
(c) Photolysis of water during photosynthesis
(d) Chlorophyll synthesis

5. Which of the following wavelength occur in the red part of the spectrum

(a) 470 *nm* (b) 390 *nm*
(c) 680 *nm* (d) 830 *nm*

6. Which of the following is photophosphorylation

(a) Production of ATP from ADP
(b) Production of NADP
(c) Synthesis of ADP from ATP
(d) Production of PGA

7. $NADPH_2$ is generated through

(a) Glycolysis (b) Photosystem-I
(c) Photosystem-II (d) Anaerobic respiration

8. The core metal of chlorophyll is

Or

Which element is left when chlorophyll is burnt

(a) Fe (b) Mg
(c) Ni (d) Cu

9. The main pigment involved in the transfer of electrons in photosynthesis is

(a) Cytochrome (b) Phytochrome
(c) Both (a) and (b) (d) None of these

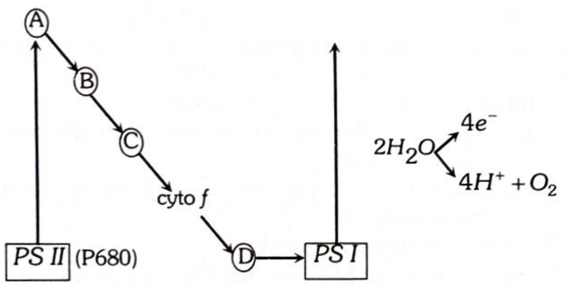
10. In noncyclic photophosphorylation, the pigment molecule first excited is
(a) P_{680} (b) P_{700}
(c) Chlorophyll–b (d) Xanthophyll

11. The reaction centre for PS-I and PS- II are
(a) P_{700} and P_{680} respectively
(b) P_{680} and P_{700} respectively
(c) P_{580} and P_{700} respectively
(d) P_{700} and P_{580} respectively

12. Photosystem–I contain
(a) Chl – a Chl – b, carotenoid and P_{680}
(b) Chl – a Chl – b and P_{690}
(c) Chl – a Chl – b and P_{700}
(d) Chl – *a* xanthophyll and P_{700}

13. Photolysis of water by isolated chloroplasts was demonstrated by
(a) Robin Hill (b) Van Niel
(c) Liebig (d) Calvin

14. Chlorophyll '*a*' and '*b*' shows maximum absorption in
(a) Blue region
(b) Red region
(c) Blue and red regions
(d) Yellow and violet regions

15.


In the above schematic diagram, which is Plastocyanin
(a) *C* (b) *D*
(c) *A* (d) *B*

16. The 'Z' scheme of photosynthesis was proposed by
(a) Hill and Bendall (b) Emerson
(c) Arnon (d) Rabinowitch and Govindjee

17. The energy required for ATP synthesis in PSII comes from
(a) Proton gradient (b) Electron gradient
(c) Reduction of glucose (d) Oxidation of glucose

18. Splitting of water is associated with
(a) Photosystem I
(b) Lumen of thylakoid
(c) Both Photosystem I and II
(d) The inner surface of the thylakoid membrane

19. The electron transport chain of the photosynthetic process is
(a) In the stroma of the chloroplast
(b) Bound to the thylakoid membranes
(c) Present in the outer membrane of the chloroplast
(d) Present in mitochondria

20. For each molecule of glucose formed in plants, the number of a molecule of *ATP* and $NADPH_2$ required are respectively
(a) 12 and 18 (b) 18 and 12
(c) 15 and 10 (d) 3 and 22

21. Stroma in the chloroplasts of the higher plant contains
(a) Light-independent reaction enzymes
(b) Light-dependent reaction enzymes
(c) Ribosomes
(d) Chlorophyll

22. Consider the following statements with respect to photosynthesis
A. The first carbon dioxide acceptor in C_4 the cycle is PGA
B. In C_3 plants, the first stable product of photosynthesis during the dark reaction is *RuBP*
C. Cyclic photophosphorylation results in the formation of ATP
D. Oxygen which is liberated during photosynthesis comes from water of the above statements
(a) A and B alone are correct
(b) A and C alone are correct
(c) C and D alone are correct
(d) B and C alone are Correct
(e) B and D alone are correct

23. Which pigment of the plant takes part in light reaction of photosynthesis

Or

Which pigment is present universally in all green plant
(a) Xanthophyll (b) Chl-a
(c) Carotene (d) Phycoxanthin

24. Ferredoxin is a component of
(a) Hill reaction (b) Photosystem–I
(c) P–680 (d) Photosystem–II

25. Which one of the following is not true about the light reactions of photosynthesis
(a) Light energy provides energy for the photolysis of water through excitation of the reaction centre of PS II
(b) The flow of electrons from water to NADP in non-cyclic electron transport produces one ATP
(c) Reactions of the two photosystems are needed for the reduction of NADP
(d) P_{680} and P_{700} are the reaction centers of PS I and PS II respectively
(e) NADPH is not produced in cyclic electron transport in light reactions

26. In chlorophyll structure, four pyrrole rings are united with Mg by their atoms of
(a) N (b) C
(c) H (d) O

27. The first acceptor of electrons from an excited chlorophyll molecule of photosystem II is
(a) Cytochrome (b) Iron-sulphur protein
(c) Ferredoxin (d) Quinone

28. Which one of the following statements about the events of noncyclic photophosphorylation is not correct
(a) Only one photosystem participates
(b) ATP and NADPH are produced
(c) Photolysis of water takes place
(d) O_2 is released

29. The source of O_2 liberated in photosynthesis in green plants is
(a) Photosynthetic enzyme
(b) Carbohydrate present in the leaf
(c) Water
(d) Carbon dioxide

30. In blue-green algae photosystem–II contains an important pigment concerned with photolysis of water it is called
(a) Beta-carotene (b) Chlorophyll '*b*'
(c) Cytochrome '*c*' (d) Phycocyanin

31. Pigment system–I receive or radiant energy and releases electron
(a) Chlorophyll–683 (b) Chlorophyll–673
(c) Chlorophyll–695 (d) P–700

32. Read the following four statements. A, B, C and D and select the right option having both correct statements.

Statements:

(A) Z scheme of light reaction takes place in presence of PS I only.

(B) Only PS I is functional in cyclic photophosphorylation

(C) Cyclic photophosphorylation results in the synthesis of ATP and $NADPH_2$

(D) Stroma lamellae lack PS II as well as NADP

Options:

(a) (B) and (D)   (b) (A) and (B)
(c) (B) and (C)   (d) (C) and (D)

33. Where does the primary photochemical reaction occur in the chloroplast or Where do the light reactions of photosynthesis take place or Light reaction takes place in
(a) Stroma
(b) Endoplasmic reticulum
(c) Quantasomes or thylakoids (Grana)
(d) The inner membrane of the chloroplast

34. The trapping centre of light energy in photosystem–I is
(a) P–660   (b) P–680
(c) P–700   (d) P–720

35. Which one of the following statements about cytochrome P_{450} is wrong
(a) It has an important role in metabolism
(b) It contains iron
(c) It is a coloured cell
(d) It is an enzyme involved in oxidation reactions

36. During photochemical reactions of photosynthesis
(a) Liberation of oxygen takes place
(b) Formation of ATP and $NADPH_2$ take place
(c) Liberation of O_2 and formation of ATP and $NADPH_2$ take place
(d) Assimilation of CO_2 takes place

37. Photo-oxidation of water results in the formation of
(a) H^+, O_2 and ATP   (b) H^+, O_2, e^- and ATP
(c) H^+, O_2 and e^- (d) None of these

38. Plants adapted to low light intensity have
(a) The more extended root system
(b) Leaves modified to spines
(c) Larger photosynthetic unit size than the sun plants
(d) The higher rate of CO_2 fixation than the sun plants

39. The light absorbed by the chlorophyll is at the wavelength of
(a) 400 *nm*   (b) 500 *nm*
(c) 600 *nm*   (d) 660 *nm*

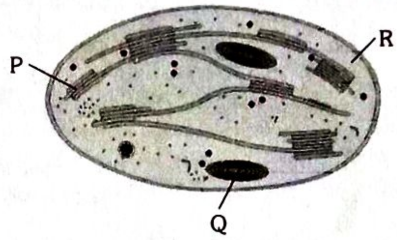
40. Number of chlorophyll arranged per reaction centre in the light-harvesting complex is
(a) 100   (b) 200
(c) 400   (d) 500

41. Which fractions of the visible spectrum of solar radiations are primarily absorbed by carotenoids of the higher plants
(a) Violet and blue   (b) Blue and green
(c) Green and red   (d) Red and violet

42. In which stage of photosynthesis, light is directly necessary
(a) For electron excitation
(b) For reduction of CO_2
(c) For regulating photosystem
(d) For cyclic photophosphorylation

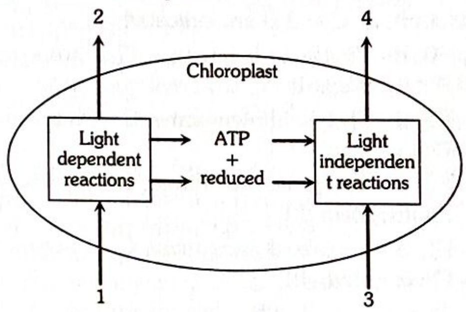
43. Hill's law in photosynthesis shows
(a) Electron excitation
(b) Removal of water
(c) Fixation of CO_2
(d) O_2 is obtained from water

44. The given diagram shows the ultrastructure of a chloroplast as seen in section. Identify the functions of P, Q and R



	P	Q	R
(a)	Light reaction	Carbohydrate synthesis	Carbohydrate storage
(b)	Light reaction	Carbohydrate storage	Carbohydrate synthesis
(c)	Light reaction	Carbohydrate synthesis	Carbohydrate storage
(d)	Carbohydrate storage	Carbohydrate synthesis	Light reaction

45. The given diagram indicates the movement of substances into in and out from chloroplast



What do labels 1 to 4 represent

	1	2	3	4
(a)	Sugar	H_2O	ATP	O_2
(b)	H_2O	O_2	CO_2	Sugar
(c)	CO_2	H_2O	Sugars	O_2
(d)	CO_2	ATP	H_2O	Starch

46. Which pigment acts directly to convert light energy to chemical energy
(a) Chlorophyll *a*   (b) Chlorophyll *b*
(c) Xanthophyll   (d) Carotenoid

47. The correct sequence of flow of electrons in the light reaction is
(a) PSII, plastoquinone, cytochromes, PSI, ferredoxin
(b) PSI, plastoquinone, cytochromes, PSII, ferredoxin
(c) PSI, ferredoxin, PSII
(d) PSI, plastoquinone, cytochromes, PSII, ferredoxin

48. Read the following four statements (*A-D*)

(A) Both, photophosphorylation and oxidative phosphorylation involve uphill transport of protons across the membrane

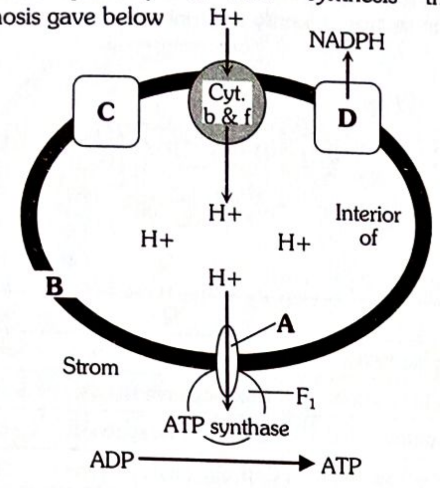
(B) In dicot stems, a new cambium originates from cells of pericycle at the time of secondary growth

(C) Stamens in flowers of Gloriosa and Petunia are polyandrous

(D) Symbiotic nitrogen-fixers occur in the free-living state also in soil

How many of the above statements are right
(a) Two   (b) Three
(c) Four   (d) One

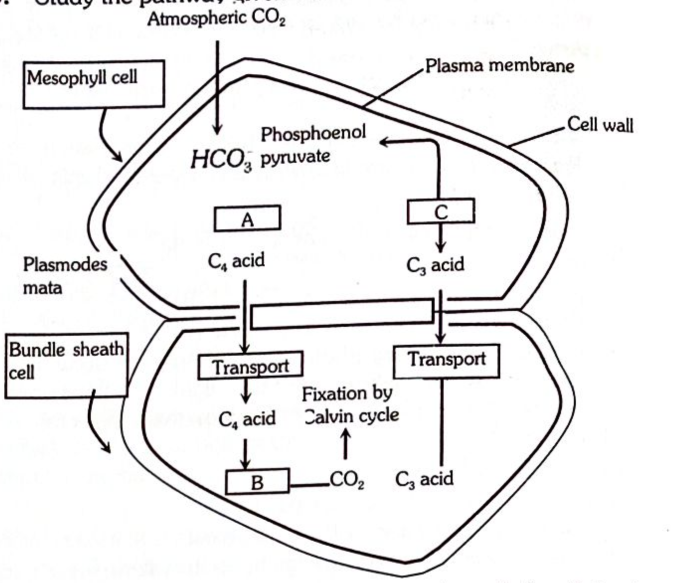
49. Observe the pathway of ATP synthesis through chemiosmosis gave below



Select the right answer in which correct words for all the four blanks A, B, C and D are indicated
(a) A - F0, B - Thylakoid membrane, C - Photosystem (II), D - Photosystem (I)
(b) A - F1, B - Thylakoid membrane, C – Photosystem (II), D - Photosystem (I)
(c) A - F0, B - Thylakoid membrane, C – Photosystem (I), D - Photosystem (II)
(d) A - F1, B - Thylakoid membrane, C – Photosystem (I), D - Photosystem (II)

5. Dark Reaction

1. The fixation and reduction of CO_2 occurring in the presence of
(a) ATP
(b) ATP and NADPH
(c) NADPH, chlorophyll and water
(d) ATP, NADPH and light
2. PGA as the first CO_2 fixation product was discovered in photosynthesis of
(a) Alga (b) Bryophyte
(c) Gymnosperm (d) Angiosperm
3. Ribulose diphosphate carboxylase oxygenase is located in
(a) Mitochondria (b) Chloroplasts
(c) Peroxisomes (d) Golgi bodies
4. The initial enzyme of the Calvin cycle is
(a) Ribulose 1, 5–diphosphate carboxylase
(b) Triose phosphate dehydrogenase
(c) Phosphopentokinase
(d) Cytochrome oxidase
5. Study the pathway given below



In which of the following options correct words for all the three blanks A, B and C are indicated

	A	B	C
(a)	Carboxylation	Reduction	Regeneration
(b)	Fixation	Transamination	Regeneration
(c)	Fixation	Decarboxylation	Regeneration
(d)	Carboxylation	Decarboxylation	Reduction

6. Calvin cycle occur in
(a) Chloroplasts (b) Cytoplasm
(c) Mitochondria (d) Glyoxysomes
7. Which of the following is present in the Calvin cycle
(a) Photophosphorylation
(b) Oxidative carboxylation
(c) Reductive carboxylation
(d) Oxidative phosphorylation
8. Reducing power which is transferred from the light reaction of photosynthesis to the dark reaction is
(a) ATP (b) NADPH
(c) NADH (d) $FADH_2$
9. The reaction that is responsible for the primary fixation of CO_2 is catalyzed by
(a) RuBP carboxylase
(b) PEP carboxylase
(c) RuBP carboxylase and PEP carboxylase
d) PGA synthase
10. During dark reaction for fixation of carbon, the three carbon atoms of each molecule of 3–phosphoglyceric acid (PGA) are derived from
(a) *RuBP* only (b) CO_2 only
(c) $RuBP + CO_2$ (d) $RuBP + CO_2 + PEP$
11. The Calvin cycle proceeds in three stages
(1) Reduction, during which carbohydrate is formed at the expense of the photochemically made ATP and NADPH
(2) Regeneration, during which the carbon dioxide acceptor ribulose–1, 5–biphosphate is formed
(3) Carboxylation, during which carbon dioxide combines with ribulose–1, 5–biphosphate Identify the correct sequence
(a) 3 – 1 – 2 (b) 3 – 2
(c) 1 – 2 – 3 (d) 2 – 1– 3
(e) 1 – 3 – 2

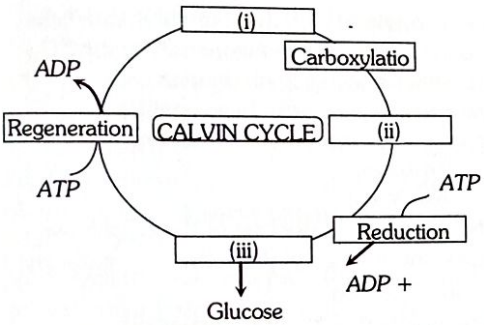
12. For the same amount of CO_2 fixed, a C_4 plant, in comparison with a C_3 plant, loses only
(a) Half the amount of water
(b) Equal amount of water
(c) Double amount of water
(d) None of these

13. CO_2 joins the photosynthetic pathway during
(a) Light reaction (b) Dark reaction
(c) Photosystem–I (d) Photosystem–II

14. Ribulose diphosphate carboxylase enzyme catalyses the carboxylation reaction between
(a) Oxaloacetic acid and acetyl CoA
(b) CO_2 and ribulose 1, 5 diphosphate
(c) Ribulose diphosphate and phosphoglyceraldehyde
(d) PGA and dihydroxy acetone phosphate

15. In C_3 plants, the first stable product of photosynthesis during dark reaction is
(a) 3–phosphoglyceric acid (b) Phosphoglyceraldehyde
(c) Malic acid (d) Oxaloacetic acid

16. Choose the correct combinations of labeling the carbohydrate molecule involved in the Calvin cycle.



(a) (i) *RuBP* (ii) Triose phosphate (iii) *PGA*
(b) (i) *PGA* (ii) *RuBP* (iii) Triose phosphate
(c) (i) *PGA* (ii) Triose phosphate (iii) *RuBP*
(d) (i) *RuBP* (ii) *PGA* (iii) Triose phosphate
(e) (i) Triose phosphate (ii) *PGA* (iii) *RuBP*

17. CO_2 acceptor in C_3 plants is
(a) Xylulose–5–phosphate
(b) 3–phosphoglyceric acid
(c) Ribulose 1, 5–diphosphate
(d) Phosphoenol pyruvic acid

18. How many Calvin cycle form one hexose molecule
(a) 2 (b) 6
(c) 4 (d) 8

19. In C_3 plants, photosynthesis occurs in
(a) Bundles sheath cells (b) Peroxisome
(c) Mesophyll cells (d) Kranz anatomy

20. In which plant Calvin experimented by radioactive isotropy to discover the stable product of C_3 cycle
(a) Chlorella (b) Cycas
(c) Carrot (d) Tobacco

21. Dark reaction in photosynthesis is called so because
(a) It can occur in dark also
(b) It does not depend on light energy
(c) It cannot occur during daylight
(d) It occurs more rapidly at night

22. The enzyme that is not found in a C_3 plant is
(a) RuBP Carboxylase (b) PEP Carboxylase
(c) NADP reductase (d) ATP synthase

23. When CO_2 is added to PEP, the first stable product synthesized is
(a) Pyruvate
(b) Glyceraldehyde-3-phosphate
(c) Phosphoglycerate
(d) Oxaloacetate

24. In C_3 cycle for the fixation of every CO_2 molecule, the reduction and regeneration steps require
(a) 3 *ATP* and 2 $NADPH_2$ (b) 2 *ATP* and 2 $NADPH_2$
(c) 2 *ATP* and 3 $NADPH_2$ (d) 3 ATP and 3 $NADPH_2$
(e) 3 *ATP* and 1 $NADPH_2$

6. C4/CAM/Photorespiration

1. An alternate CO_2 fixation mechanism was found some tropical species of grass family by Hatch and Slack, who were from
(a) England (b) the USA
(c) Australia (d) New Zealand

2. Which of the following statements with regard to photosynthesis is/are correct
A. In C_4 plants, the primary CO_2 acceptor is PEP
B. In the photosynthetic process, PS II absorbs energy at or just below 680 nm
C. The pigment that is present in the pigment system I am P_{683}
(a) B and C only (b) A only
(c) C only (d) A and B only
(e) A and C only

3. The ratio between 2-carbon and 3-carbon intermediates having $-NH_2$ group formed in photosynthetic oxidation cycle is
(a) 1 : 1 (b) 2 : 1
(c) 3 : 2 (d) 3 : 4

4. In photorespiration, what is the role of peroxisome
(a) Help in the oxidation of glycolate
(b) Help in oxygenation of glycolate
(c) Help in the synthesis of *PGA*
(d) Help in the reduction of glyoxylate

5. In a CAM plant the concentration of organic acid
(a) Increases during the day
(b) Decreases or increases during the day
(c) Increases during night
(d) Decreases during any time

6. During photorespiration, the oxygen-consuming reaction (s) occur in
(a) Grana of chloroplasts and peroxisomes
(b) Stroma of chloroplasts
(c) Stroma of chloroplasts and mitochondria
(d) Stroma of chloroplasts and peroxisomes

7. Photorespiration is characteristic of
(a) CAM Plants (b) C_3 Plants
(c) C_4 Plants (d) None of the above

8. In C_4 plants, Calvin cycle occurs in
(a) Stroma of bundle sheath chloroplast
(b) Mesophyll chloroplast
(c) Grana of bundle sheath chloroplast
(d) Does not occur as CO_2 is fixed mainly by PEP and no CO_2 is left for Calvin cycle

9. C_4 plants are adapted to
(a) Hot and dry climate (b) Temperate climate
(c) Cold and dry climate (d) Hot and humid climate

10. In the leaves of C_4 plants, malic acid formation during CO_2 fixation occurs in the cells of
(a) Mesophyll (b) Bundle Sheath
(c) Phloem (d) Epidermis

11. Which crop utilizes solar energy most efficiently
(a) Potato (b) Sugarcane
(c) Wheat (d) Rice

12. In maximum plants stomata open during the day and closed in the night. Its exception is
(a) Crassulacean acid metabolism plants
(b) C_3 plants
(c) C_4 plants
(d) None of these

13. Source of CO_2 for photosynthesis during the day in CAM plant is
(a) 3-PGA (b) Malic acid
(c) Oxalo-acetic acid (d) Pyruvate

14. Sugarcane show high efficiency of CO_2 fixation because of
(a) Calvin cycle (b) Hatch and Slack cycle
(c) TCA cycle (d) Greater sunlight

15. In sugarcane plant $^{14}CO_2$ is fixed in malic acid, in which the enzyme that fixes CO_2 is
(a) Fructose phosphatase
(b) Ribulose bisphosphate carboxylase
(c) Phosphoenol pyruvate carboxylase
(d) Ribulose phosphate kinase

16. In the Hatch and Slack pathway
(a) Chloroplast is of the same type
(b) Occurs in Kranz anatomy where mesophyll have small chloroplast whereas bundle sheath have agranal chloroplast
(c) Occurs in Kranz anatomy when mesophyll have small chloroplast where a bundle sheath have larger chloroplast
(d) Kranz anatomy where mesophyll cell are diffused

17. The first reaction in photorespiration is
(a) Carboxylation (b) Decarboxylation
(c) Oxygenation (d) Phosphorylation

18. In photorespiration, glycolate is converted to CO_2 and serine in
(a) Chloroplasts (b) Peroxisomes
(c) Vacuoles (d) Mitochondria

19. CAM helps the plants in
(a) Reproduction (b) Conserving water
(c) Secondary growth (d) Disease resistance

20. What is called Warburg's effect on photosynthesis
(a) The low rate of the process due to O_2 supply
(b) The low rate of the process due to CO_2 supply
(c) Both (a) and (b)
(d) None of the above

21. PEP is the primary CO_2 acceptor in
(a) C_4 Plants (b) C_3 plants
(c) C_2 Plants (d) Both C_3 and C_4 plants

22. How many molecules of glycine is required to release one CO_2 molecule in photorespiration
(a) One (b) Two
(c) Three (d) Four

23. The first product of CO_2 fixation in Hatch and Slack (C_4) cycle in plants is
(a) Formation of oxaloacetate by carboxylation of phosphoenolpyruvate (PEP) in bundle sheath cells
(b) Formation of phosphoglyceric acid in mesophyll cells
(c) Formation of bundle sheath cells
(d) Formation of oxaloacetate by carboxylation of phosphoenolpyruvate (PEP) in the mesophyll cells

24. The C_4 plants are different from C_3 plants with reference to the
(a) A substance that accepts CO_2 in carbon assimilation
(b) Type of end product of photosynthesis
(c) Number of *ATP* that is consumed in preparing sugar
(d) Types of pigments involved in photosynthesis

25. Which one is a C_4 plant
(a) Papaya (b) Pea
(c) Potato (d) Maize

26. Dimorphism of the chloroplast is found
(a) C_4 plants (b) C_3 plants
(c) CAM plants (d) All the above

27. Select the incorrectly matched pair with regard to C_4 cycle
(a) Primary CO_2 fixation product - PGA
(b) Site of initial carboxylation - Mesophyll cells
(c) Primary CO_2 acceptor - PEP
(d) C_4 plant - Maize
(e) Location of enzyme RuBisCO - Bundle sheath cells

28. Which of the following is a 4-carbon compound
(a) Oxaloacetic acid (b) Phosphoglyceric acid
(c) Ribulose bisphosphate (d) Phosphoenolpyruvate
(e) Citric acid

29. Photorespiration is favoured by
(a) Low light and high O_2
(b) Low O_2 and high CO_2
(c) Low temperature and high O_2
(d) High O_2 and low CO_2

30. Photosynthesis in C_4 plants is relatively less limited by atmospheric CO_2 levels because
(a) Four carbon acids are the primary initial CO_2 fixation products
(b) The primary fixation of CO_2 is mediated via PEP carboxylase
(c) Effective pumping of CO_2 into bundle sheath cells
(d) RuBisCo in C_4 plants has a higher affinity for CO_2

31. CAM photosynthesis occurs in plants with
(a) Thin green leaves with reticulate venation
(b) Thin green leaves with parallel venation
(c) Fleshy green leaves
(d) Thin coloured leaves

32. Which of the statements is not true of the C_4 pathway
(a) It requires more energy than the C_3 pathway for the production of glucose
(b) It overcomes loss due to photorespiration
(c) The CO_2 acceptor is a C_3 compound
(d) It is inhibited by a high CO_2 concentration

33. The enzyme which catalyzes the photosynthetic C_4 cycle i

Or

In C_4 plants, CO_2 combines with PEP in presence of
(a) RuDP carboxylase (b) PEP carboxylase
(c) Carbonic anhydrase (d) None of these

34. Peroxisomes are found in
(a) Bundle sheath (b) Endosperm
(c) Mesophyll cells (d) Vascular bundle

35. In Kranz anatomy, the bundle sheath cells have
(a) Thin walls, no intercellular spaces and several chloroplasts
(b) Thick walls, many intercellular spaces and few chloroplasts
(c) Thin walls, many intercellular spaces and no chloroplasts
(d) Thick walls, no intercellular spaces and a large number of chloroplasts

36. As compared to a C_3 plant, how many additional molecules of ATP are needed for the net production of one molecule hexose sugar by C_4 plants
(a) Two (b) Six
(c) Zero (d) Twelve

37. Which of the following is formed during photorespiration
(a) Sugar (b) Phosphoglycolate
(c) ADPH (d) ATP
(e) Oxaloacetate

38. Which of the option is correct for photorespiration
(a) In chloroplast, glycerate forms glycine
(b) In peroxisome, glycerate forms phosphoglycolate
(c) In mitochondrion, glycine forms serine
(d) In bundle sheath, serine form glycine

7. Bacterial photosynthesis

1. Leptothrix is a
   (a) Nitrifying bacteria (b) Sulphur bacteria
   (c) Iron bacteria (d) Hydrogen bacteria
2. The site of photosynthesis in blue-green algae is
   (a) Chromatophores (b) Mitochondria
   (c) Chloroplast (d) Root hair
3. Which was the first photosynthetic organism
   (a) Green algae (b) Red algae
   (c) Cyanobacteria (d) None of these
4. All life on earth derives its energy directly or indirectly from sun except
   (a) Mushroom and mould (b) Chemosynthetic bacteria
   (c) Symbiotic bacteria (d) Pathogenic bacteria
5. Chlorophyll *a* is absent in which of the following photosynthetic organism
   (a) Cyanobacteria (b) Red algae
   (c) Brown algae (d) Bacteria
6. Bacteriochlorophyll differs from chlorophyll '*a*' in having
   (a) One pyrrole ring with one hydrogen
   (b) One pyrrole ring with two hydrogen
   (c) One pyrrole ring with three hydrogen
   (d) One pyrrole ring with four hydrogen
7. Bacterial photosynthesis takes place in
   (a) Cytoplasm (b) Chromoplast
   (c) Chloroplast (d) Oxysome
8. Which of the following photosynthetic bacteria have both PS–I and PS–II
   (a) Green sulphur bacteria (b) Purple sulphur bacteria
   (c) Cyanobacteria (d) Purple non-sulphur bacteria

8. Factors affecting photosynthesis

1. Compensation point is
   (a) Where there is neither photosynthesis nor respiration
   (b) When the rate of photosynthesis is equal to the rate of respiration
   (c) When entire food synthesized into photosynthesis remain utilized
   (d) When there is enough water just to meet the requirements of the plant
2. The most effective wavelength of visible light in photosynthesis is in the region of
   (a) Violet (b) Green
   (c) Yellow (d) Red
3. In which of the following the rate of photosynthesis is decreased and is known as red drop
   (a) Blue light
   (b) Greenlight
   (c) Red light more than 680 *nm*
   (d) Red light less than 680 *nm*
4. Which of the following can photosynthesize at low temperature ($-20°C$)
   (a) Bacteria (b) Lichen
   (c) Yeast (d) Batrachospermum
5. Which factor is not limiting in normal conditions for photosynthesis
   (a) Air (b) CO_2
   (c) Water (d) Chlorophyll
6. If the rate of translocation of food is slow, what will be the effect on photosynthesis
   (a) It will increase (b) It will remain the same
   (c) Becomes double (d) It will decrease
7. Chl. *a* absorbs max of
   (a) Red light (b) Blue light
   (c) Green light (d) Yellow light
8. Which of the following conditions are favorable for cyclic photophosphorylation
   (a) Anaerobic condition
   (b) Aerobic and optimum light
   (c) Aerobic and low light intensity
   (d) Anaerobic and low light intensity
9. Plants which can photosynthesize at an as low temperature (up to $-35° C$) are
   (a) Conifers (b) Blue-green algae
   (c) Xerophytes (d) Tropical plants
10. The optimum temperature for Photosynthesis is
   (a) 10 – 15°C (b) 20 – 25°C
   (c) 25 – 30°C (d) 35 – 40°C

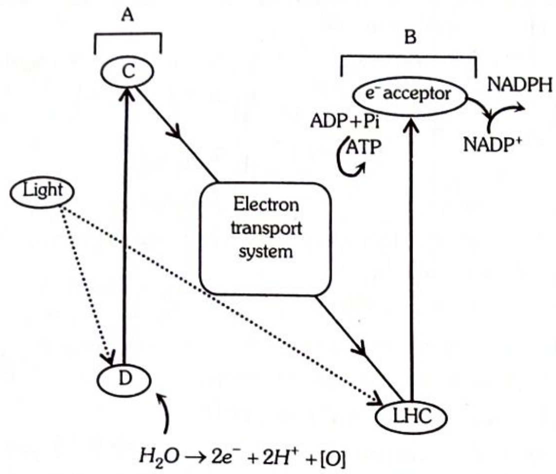
9. NEET- AIPMT/ CBSC-PMT

1. Emerson's enhancement effect and Red drop have been instrumental in the discovery of **[2016]**
   (a) Photophosphorylation and non-cyclic electron transport
   (b) Two photosystems operating simultaneously
   (c) Photophosphorylation and cyclic electron transport
   (d) Oxidative phosphorylation
2. In a chloroplast, the highest number of protons are found in **[2016]**
   (a) Stroma (b) Lumen of thylakoids
   (c) Intermembrane space (d) Antennae complex
3. Which of the following pigment is soluble in water **[2016]**
   (a) Chlorophyll (b) Carotene
   (c) Anthocyanin/Phycobilins (d) Xanthophyll
4. Which of the following is not a produce of light reaction of photosynthesis **[2018]**
   (a) Oxygen (b) NADPH
   (c) NADH (d) ATP
5. In C_4 plants, the bundle sheath cells **[2013]**
   (a) Have thin walls of facilitating the gaseous exchange
   (b) Have large intercellular spaces
   (c) Are rich in PEP carboxylase
   (d) Have a high density of chloroplasts and rich in RuBisCo
6. 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 utilization. In which of the following physiological groups would you assign this plant **[2016]**
   (a) C_3 (b) C_4
   (c) CAM (d) Nitrogen fixer

10. AIIMS

1. Intact chloroplast from green leaves can be isolated by **[1990]**
   (a) Acetone (b) Ethanol
   (c) Alcohol (d) Sugar solution

2.



Which of the following is correctly labeled for the given figure **[2012]**

(a) A: PS II; B: PS I; C: e^-acceptor; D: LHC

(b) A: LHC; B: e^-acceptor; C: PS I; D: PS II

(c) A: PSI; B: PS II; C: e^-acceptor; D: LHC

(d) A: e^-acceptor; B: LHC; C: PS II; D: PS I

3. Hill reaction occurs in **[2003]**

(a) High altitude plants (b) Total darkness

(c) Absence of water (d) Presence of ferredoxin

4. Photosynthetically active radiation (PAR) represents the following range of wavelength **[2007]**

(a) 340–450 *mm* (b) 400–700 *mm*

(c) 500–600 *mm* (d) 450–950 *mm*

5. The C_4 plants are photosynthetically more efficient than C_3 plants because **[2011]**

(a) The CO_2 efflux is not prevented

(b) They have dimorphic chloroplast

(c) The CO_2 compensation point is more

(d) CO_2 generated during photorespiration is trapped and recycled through PEP carboxylase

6. Photorespiration shows the formation of **[2012]**

(a) Sugar but not ATP (b) ATP but not sugar

(c) Both ATP and sugar (d) Neither ATP nor sugar

7. Kranz type of anatomy is found in **[2012]**

(a) C_2 plants (b) C_3 plants

(c) C_4 plants (Sugarcane) (d) CAM plants

8. The glycolate metabolism occur in **[2001]**

(a) Lysosomes (b) Ribosomes

(c) Glyoxysomes (d) Peroxisomes

9. Photorespiration takes place is **[2001]**

(a) Chloroplast, mitochondria

(b) Mitochondria, peroxysome

(c) Chloroplasts, peroxysome, mitochondria

(d) Chloroplasts, cytoplasm, mitochondria

10. Which one of the following categories of organisms do not evolve oxygen during photosynthesis **[2004]**

(a) Red algae

(b) Photosynthetic bacteria

(c) C_4 plants with Kranz anatomy

(d) Blue-green algae

11. Blackman's law of limiting factor is applied to **[2001]**

(a) Growth (b) Respiration

(c) Transpiration (d) Photosynthesis

11. Assertion & Reason

Read the assertion and reason carefully to mark the correct option out of the options given below :

(a) If both the assertion and the reason are true and the reason is a correct explanation of the assertion

(b) If both the assertion and reason are true but the reason is not a correct explanation of the assertion

(c) If the assertion is true but the reason is false

(d) If both the assertion and reason are false

(e) If the assertion is false but reason is true

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

2. Assertion : C4 photosynthetic pathway is more efficient than the 3 C_3 pathway.
   Reason : Photorespiration is suppressed in C_4 plants.

3. Assertion : The stromal thylakoids are rich in both PS I and PS II.
   Reason : The granal membranes are rich in ATP synthetase.

4. Assertion : CO_2 is transported from mesophyll cells to bundle sheath of chloroplasts in C_4 plants.
   Reason : *RuBP* is called final acceptor of CO_2 in C_4 plants.

5. Assertion : C_4 pathway of CO_2 fixation is found in some tropical plants.
   Reason : In this pathway, CO_2 is fixed by the 3C compound.

6. Assertion : Rhoeo leaves contain anthocyanin pigments in epidermal cells.
   Reason : Anthocyanin is accessory photosynthetic pigments.

7. Assertion : CAM plants lack structural compartmentation of leaf, as found in C_4 plants.
   Reason : Stomata of CAM plants are open during the day.

8. Assertion : Cyclic pathway of photosynthesis first appeared in some eubacterial species.
   Reason : Oxygen started accumulating in the atmosphere after the non-cyclic pathway of photosynthesis evolved.

9. Assertion : Each molecule of ribulose-1, 5-biphosphate fixes one molecule of CO_2.
   Reason : Three molecules of NADPH and two ATP are required for fixation of one molecule of CO_2.

10. Assertion : Sciophytes require higher light intensity than heliophytes.
    Reason : Sciophytes grow below the canopy of trees.