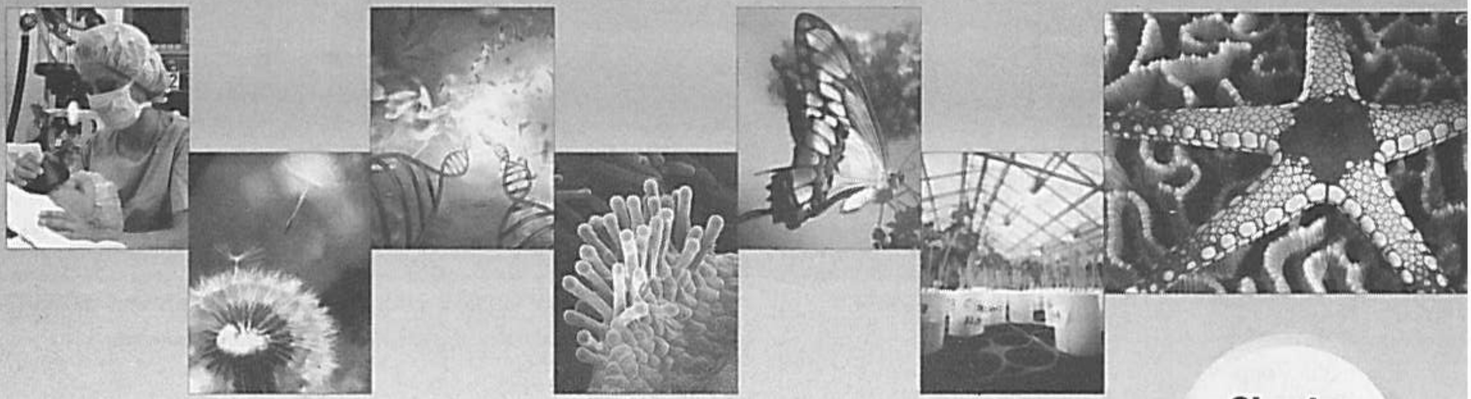


Chapter
4.3

Photosynthesis in Higher Plants

In photosynthesis process, 'energy rich compounds like carbohydrates are synthesized from simple inorganic compounds like carbon dioxide and water in the presence of chlorophyll and sunlight with liberation of oxygen'. The process of photosynthesis can also be defined as "transformation of photonic energy (i.e., light or radiant energy) into chemical energy".

About 90% of total photosynthesis in world is done by algae in oceans and in freshwater. More than 170 billion tonnes of dry matter are produced annually by this process. Further CO_2 fixed annually through photosynthesis is about $7.0 \times 10^{13} kg$. Photosynthesis is a reductive, anabolic and endothermic reaction. Photosynthesis helps to maintain the equilibrium position of O_2 and CO_2 in the atmosphere.

Historical background

Before seventeenth century it was considered that plants take their food from the soil.

- **Van Helmont** (1648) concluded that all food of the plant is derived from water and not from 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** (1772) demonstrated that green plants (mint plant) purify the foul air (*i.e.*, Phlogiston), produced by burning of candle, and convert it into pure air (*i.e.*, Dephlogiston).
- **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.
- **Jean Senebier** (1782) proved that plants absorb CO_2 and release O_2 in the presence of light. He also showed that the rate of O_2 evolution depends upon the rate of CO_2 consumption.
- **Nicolus de Saussure** (1804) showed the importance of water in the process of photosynthesis. He further showed that the amount of CO_2 absorbed is equal to the amount of O_2 released.
- **Julius Robert Mayer** (1845) proposed that light has radiant energy and this radiant energy is converted to chemical energy by plants, which serves to maintain life of the plants and also animals.
- **Liebig** (1845) indicated that main source of carbon in plants is CO_2.
- **Bousingault** (1860) reported that the volume of CO_2 absorbed is equal to volume of O_2 evolved and that CO_2 absorption and O_2 evolution get start immediately after the plant was exposed to sunlight.
- **Julius Von Sachs** (1862) demonstrated that first visible product of photosynthesis is starch. He also showed that chlorophyll is confined to the chloroplasts.
- **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.
- **Huber, Michel** and **Deisenhofer** (1985) crystallised the photosynthetic reaction center from the purple photosynthetic bacterium, *Rhodopseudomonas viridis*. They analysed its structure by X-ray diffraction technique. In 1988 they were awarded Nobel prize in chemistry for this work.

Photosynthesis in higher plants

Chloroplast (The site of photosynthesis) : Chloroplast are green plastids which function as the site of photosynthesis in eukaryotic photoautotrops. It fixes CO_2 into carbohydrate.

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.

Chloroplast 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 (fret membrane). There is a wide range of chloroplastic pigments which constitute more than 5% of the total dry weight of the chloroplast. They are grouped under two main categories :

(1) **Chlorophylls :** Chlorophyll '*a*' is found in all the oxygen evolving photosynthetic plants except photosynthetic bacteria. Reaction centre of photosynthesis is formed of chlorophyll *a*. It occurs in several spectrally distinct forms which perform distinct roles in photosynthesis (*e.g.*, Chl a_{680} or P_{680}, Chl a_{700} or P_{700}, etc.). It directly takes part in photochemical reaction. Hence, it is termed as primary photosynthetic pigment. Other photosynthetic pigments including chlorophyll *b*, *c*, *d* and *e* ; carotenoids and phycobilins are called accessory pigments because they do not directly take part in photochemical act. They absorb specific wavelengths of light and transfer energy finally to chlorophyll *a* through electron spin resonance.

Chlorophyll *a* is bluish-green while chlorophyll *b* is olive-green. Both are soluble in organic solvents like alcohol, acetone etc. Chlorophyll is a green pigment because it does not absorb green light (but reflect green light) Chlorophyll *a* ($C_{55}H_{72}O_5N_4Mg$) possesses — CH_3 (methyl group), which is replaced by — CHO (an aldehyde) group in chlorophyll *b* ($C_{55}H_{70}O_6N_4Mg$). Chlorophyll molecule is made up of a squarish tetrapyrrolic ring known as head and a phytol alcohol called tail. The magnesium atom is present in the central position of tetrapyrrolic ring. The four pyrrole rings of porphyrin head are linked together by methine ($CH =$) groups forming a ring system.

When central *Mg* is replaced by *Fe*, the chlorophyll becomes a green pigment called 'cytochrome' which is used in photosynthesis (Photophosphorylation) and respiration both.

(2) **Carotenoids :** They are sometimes called lipochromes due to their fat soluble nature. They are lipids and found in non-green parts of plants. Light is not necessary for their biosynthesis. Carotenoids mainly absorb violet, indigo and blue wavelength of spectrum in higher plants 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.

(i) **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.

(ii) **Xanthophylls :** They are yellow coloured carotenoid also called xanthols or carotenols. They contain oxygen also along with carbon and hydrogen and have general formula $C_{40}H_{56}O_2$.

Lutein ($C_{40}H_{56}O_2$) a widely distributed xanthophyll which is responsible for yellow colour in autumn foliage. Fucoxanthin ($C_{40}H_{56}O_6$) is another important xanthophyll present in Phaeophyceae (Brown algae).

(3) **Phycobilins :** These pigments are mainly found in blue-green algae (Cyanobacteria) and red algae. These pigments have open tetrapyrrolic in structure and do not bear magnesium and phytol chain.

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*.

Nature of light : Sunlight is a type of energy called radiant energy or electromagnetic energy. This energy, according to electromagnetic wave theory (Proposed by James Clark Maxwell, 1960), travels in space as waves. The distance between the crest of two adjacent waves is called a wavelength (λ). Shorter the wavelength greater the energy.

The unit quantity of light energy in the quantum theory is called quantum (hv), whereas the same of the electromagnetic field is called photon. Solar radiation can be divided on the basis of wavelengths. Radiation of shortest wavelength belongs to cosmic rays whereas that of longest wavelength belong to radio waves. Visible light lies between wavelengths of ultra-violet and infra-red. The visible spectrum of solar radiations are primarily absorbed by carotenoids of the higher plants are violet and blue. However, out of blue and red wavelengths, blue light carry more energy.

Shortest wavelength ⟶ Longest wavelength
Maximum energy — Minimum energy

Visible light : 390*nm* (3900Å) to 760*nm* (7600Å). Violet (390–430*nm*), blue (430–470*nm*), blue-green (470–500*nm*), green (500–580*nm*), yellow (580–600*nm*), orange (600–650*nm*), orange-red (650–660*nm*) and red (660–760*nm*) Far-red (700–760*nm*). Infra-red 760*nm* – 100μm. Ultraviolet 100–390*nm*. Solar radiations 300*nm* (ultraviolet) to 2600*nm* (infra-red).

Photosynthetically active radiation (PAR) is 400–700*nm*. Leaves appear green because chlorophylls do not absorb green light. The same is reflected and transmitted through leaves.

Absorption and action spectra : The curve representing the light absorbed at each wavelength by pigment is called absorption spectrum. Curve showing rate of photosynthesis at different wavelengths of light is called action spectrum.

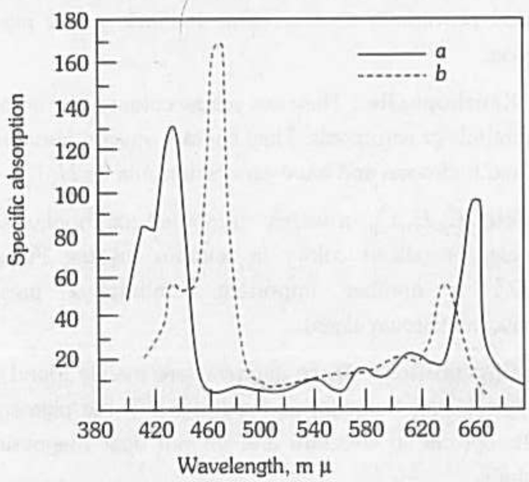


Fig : 4.3-1 Absorption spectra of chlorophylls a and b

Absorption spectrum is studied with the help of spectrophotometer. The absorption spectrum of chlorophyll *a* and chlorophyll *b* indicate that these pigments mainly absorb blue and red lights. (430 *nm* and 662 *nm* for chlorophyll *a*, 455 *nm* and 644 *nm* for chlorophyll *b*). Action spectrum shows that maximum photosynthesis takes place in blue and red regions of spectrum. The first action spectrum of photosynthesis was studied by T.W. Engelmann (1882) using green alga *Spirogyra* and oxygen seeking bacteria.

In this case actual rate of photosynthesis in terms of oxygen evolution or carbon dioxide utilisation is measured as a function of wavelength.

Mechanism of photosynthesis

On the basis of discovery of Nicolas de Saussure that "The amount of O_2 released from plants is equal to the amount of CO_2 absorbed by plants", it was considered that O_2 released in photosynthesis comes from CO_2, but Ruben proved that this concept is wrong.

In 1930, C.B. Van Niel proved that, sulphur bacteria use H_2S (in place of water) and CO_2 to synthesize carbohydrates as follows:

$$6CO_2 + 12H_2S \longrightarrow C_6H_{12}O_6 + 6H_2O + 12S$$

This led Van Niel to the postulation that in green plants, water (H_2O) is utilized in place of H_2S and O_2 is evolved in place of sulphur (S). He indicated that water is an electron donor in photosynthesis.

$$6CO_2 + 12H_2O \longrightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$$

This was confirmed by Ruben and Kamen in 1941 using *Chlorella* a green alga.

They used isotopes of oxygen in water, *i.e.*, $H_2^{18}O$ instead of H_2O (normal) and noticed that liberated oxygen contains ^{18}O of water and not of CO_2. The overall reaction can be given as under :

$$6CO_2 + 12H_2{}^{18}O \xrightarrow[\text{Chlorophyll}]{\text{Light}} C_6H_{12}O_6 + 6^{18}O_2 + 6H_2O$$

During photosynthesis the O_2 in glucose comes from carbondiowater.

Modern concept of photosynthesis

Photosynthesis is an oxidation reduction process in which water is oxidised to release O_2 and CO_2 is reduced to form starch and sugars.

Scientists have shown that photosynthesis is completed in two phases.

(1) **Light phase or Photochemical reactions or Light dependent reactions or Hill's reactions :** During this stage energy from sunlight is absorbed and converted to chemical energy which is stored in ATP and $NADPH + H^+$.

(2) **Dark phase or Chemical dark reactions or Light independent reactions or Blackman reaction or Biosynthetic phase :** During this stage carbohydrates are synthesized from carbon dioxide using the energy stored in the ATP and NADPH formed in the light dependent reactions.

Evidence for light and dark reactions in photosynthesis :

(1) **Physical separation of chloroplast into grana and stroma fractions :** It is now possible to separate grana and stroma fractions of chloroplast. If light is given to grana fraction in presence of suitable H-acceptor and in complete absence of CO_2, then ATP and $NADPH_2$ are produced (*i.e.*, assimilatory powers). If these assimilatory powers (ATP and $NADPH_2$) are given to stroma fraction in presence of CO_2 and absence of light, then carbohydrates are formed.

(2) **Experiments with intermittent light or Discontinuous light :** Rate of photosynthesis is faster in intermittent light (Alternate light and dark periods) than in continuous light. It is because light reaction is much faster than dark reaction, so in continuous light, there is accumulation of ATP and $NADPH_2$ and hence reduction in rate of photosynthesis but in discontinuous light, ATP and $NADPH_2$ formed in light are fully consumed during dark in reduction of CO_2 to carbohydrates. Accumulation of $NADPH_2$ and ATP is prevented because they are not produced during dark periods.

(3) **Temperature coefficient studies :** Blackman found that Q_{10} was greater than 2 in experiment when photosynthesis was rapid and that Q_{10} dropped from 2 often reaching unity, *i.e.*, 1 when the rate of photosynthesis was low. These results show that in photosynthesis there is a dark reaction (Q_{10} more than 2) and a photochemical or light reaction (with Q_{10} being unity).

$$Q_{10} = \frac{\text{Reaction rate of } (t+10)°C}{\text{Reaction at } t°C}$$

Light reaction (Photochemical reactions) : Light reaction occurs in grana fraction of chloroplast and in this reaction are included those activities, which are dependent on light. Assimilatory powers (ATP and $NADPH_2$) are mainly produced in this light reaction.

Robin Hill (1939) first of all showed that if chloroplasts extracted from leaves of *Stellaria media* and *Lamium album* are suspended in a test tube containing suitable electron acceptors, *e.g.*, Potassium ferroxalate (Some plants require only this chemical) and potassium ferricyanide, oxygen is released due to photochemical splitting of water. Under these conditions, no CO_2 was consumed and no carbohydrate was produced, but light-driven reduction of the electron acceptors was accompained, by O_2 evolution.

$$\underset{\text{Electron acceptor}}{4Fe^{3+}} + \underset{\text{Electron donor}}{2H_2O} \longleftrightarrow \underset{\text{Reduced Product}}{4Fe^{2+}} + 4H^+ + O_2 \uparrow$$

The splitting of water during photosynthesis is called photolysis. This reaction on the name of its discoverer is known as Hill reaction.

Hill reaction proves that

(1) In photosynthesis oxygen is released from water.

(2) Electrons for the reduction of CO_2 are obtained from water [*i.e.*, a reduced substance (hydrogen donor) is produced which later reduces CO_2].

Dichlorophenol indophenol is the dye used by Hill for his famous Hill reaction.

According to Arnon (1961), in this process light energy is converted to chemical energy. This energy is stored in ATP (this process of ATP formation in chloroplasts is known as photophosphorylation) and from electron acceptor NADP$^+$, a substance found in all living beings NADP*H is formed as hydrogen donor. Formation of hydrogen donor NADPH from electron acceptor NADP$^+$ is known as photoreduction or production of reducing power NADPH.

Light phase can be explained under the following headings :

(1) **Transfer of energy :** When photon of light energy falls on chlorophyll molecule, one of the electrons pair from ground or singlet state passes into higher energy level called excited singlet state. It comes back to hole of chlorophyll molecule within 10^{-9} seconds.

This light energy absorbed by chlorophyll molecule before coming back to ground state appears as radiation energy, while that coming back from excited singlet state is called fluorescence and is temperature independent. Sometimes the electron at excited singlet state gets its spin reversed because two electrons at the same energy level cannot stay; for sometime it fails to return to its partner electron. As a result it gets trapped at a high energy level. Due to little loss of energy, it stays at comparatively lower energy level (Triplet state) from excited singlet state. Now at this moment, it can change its spin and from this triplet state, it comes back to ground state again losing excess of energy in the form of radiation. This type of loss of energy is called as phosphorescence.

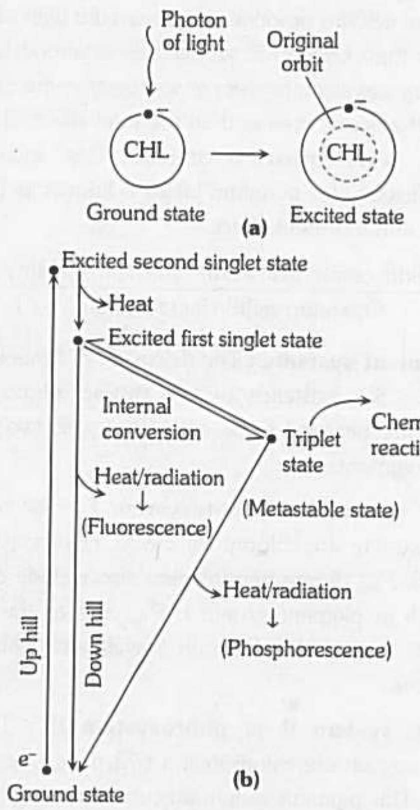


Fig : 4.3-2 (a) Photoexcitation of chlorophyll molecule *i.e.*, of its atoms (b) Movement of electron due to photoexcitation of pigment molecule

When electron is raised to higher energy level, it is called at second singlet state. It can lose its energy in the form of heat also. Migration of electron from excited singlet state to ground state along with the release of excess energy into radiation energy is of no importance to this process. Somehow when this excess energy is converted to chemical energy, it plays a definite constructive role in the process.

(2) **Quantum yield**

(i) Rate or yield of photosynthesis is measured in terms of quantum yield or O_2 evolution, which may be defined as, "Number of O_2 molecules evolved per quantum of light absorbed in photosynthesis."

(ii) Quantum requirement in photosynthesis = 8, *i.e.*, 8 quanta of light are required to evolve one mol. of O_2.

(iii) Hence quantum yield = 1 / 8 = 0.125 (*i.e.*, a fraction of 1) as 12%.

(3) **Emerson effect and Red drop :** R. Emerson and C.M. Lewis (1943) observed that the quantum yield of photosynthesis decreases towards the far red end of the

spectrum (680*nm* or longer). Quantum yield is the number of oxygen molecules evolved per light quantum absorbed. Since this decrease in quantum yield is observed at the far region or beyond red region of spectrum is called red drop.

Emerson *et al.* (1957) further observed that photosynthetic efficiency of light of 680*nm* or longer is increased if light of shorter wavelengths (Less than 680*nm*) is supplied simultaneously. When both short and long wavelengths were given together the quantum-yield of photosynthesis was greater than the total effect when both the wavelengths were given separately. This increase in photosynthetic efficiency (or quantum yield) is known as Emerson effect or Emerson enhancement effect.

$$E = \frac{\text{Quantum yield in combined beam} - \text{Quantum yield in red beam}}{\text{Quantum yield in far red beam}}$$

(4) **Two pigment systems :** The discovery of Emerson effect has clearly shown the existence of two distinct photochemical processes, which are believed to be associated with two different specific group of pigments.

(i) **Pigment system I or Photosystem I :** The important pigments of this system are chlorophyll *a* 670, chlorophyll *a* 683, chlorophyll *a* 695, P_{700}. Some physiologists also include carotenes and chlorophyll *b* in pigment system I. P_{700} acts as the reaction centre. Thus, this system absorbs both wavelengths shorter and longer than 680*nm*.

(ii) **Pigment system II or photosystem II :** The main pigments of this system are chlorophyll *a* 673, P_{680}, chlorophyll *b* and phycobilins. This pigment system absorbs wavelengths shorter than 680*nm* only. P_{680} acts as the reaction centre.

Pigment system 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.

Table : 4.3-1 Comparison of photosystem I and photosystem II

S. No.	Photosystem I	Photosystem II
(1)	PS I lies on the outer surface of the thylakoids.	PS II lies on the inner surface of the thylakoid.
(2)	In this system molecular oxygen is not evolved.	As the result of photolysis of water molecular oxygen is evolved.
(3)	Its reaction center is P700.	Its reaction center is P680.
(4)	It participates both in cyclic and noncyclic photophosphorylation.	It participates only in noncyclic photophosphorylation.
(5)	It receives electrons from photosystem II.	It receives electrons from photolytic dissociation of water.
(6)	It is not related with photolysis of water.	It is related with photolysis of water.

(5) **Photophosphorylation :** Light phase includes the interaction of two pigment systems. PS I and PS II constitute various type of pigments. Arnon showed that during light reaction not only reduced NADP is formed and oxygen is evolved but ATP is also formed. This formation of high energy phosphates (ATP) is dependent on light hence called photophosphorylation.

Photophosphorylation is of two types :

(i) **Cyclic photophosphorylation :** The system is found dominantly in bacteria. It involves only PS I. Flow of electron is cyclic. If NADP is not available then this process will occur. When the photons activate PS I, a pair of electrons are raised to a higher energy level. They are captured by primary acceptor which passes them on to ferredoxin, plastoquinone, cytochrome complex, plastocyanin and finally back to reaction centre of PS I *i.e.*, P_{700}. At each step of electron transfer, the electrons lose potential energy. Their trip down hill is caused by the transport chain to pump H^+ across the thylakoid membrane. The proton gradient, thus established is responsible for forming (2 molecules) ATP. No reduction of NADP to NADPH+ H^+. ATP is synthesized at two steps.

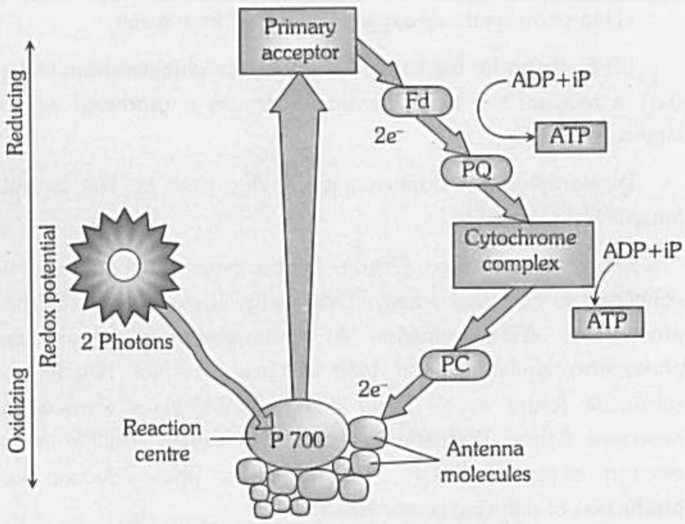


Fig : 4.3-3 Cyclic photophosphorylation

(ii) **Non cyclic photophosphorylation :** The system is dominant in green plants. It involves both PS-I and PS-II. Flow of electrons is unidirectional. Here electrons are not cycled back and are used in the reduction of NADP to $NADPH_2$. Here H_2O is utilized and O_2 evolution occurs. In this chain high energy electrons released from 'P-680' do not return to 'P-680' but pass through pheophytin, plastoquinone, cytochrome b_6-*f* complex, plastocyanin (*Cu* containing pigment) and then enter P-700. In this transfer of electrons from plastoquinone (PQ) to cytochrome b_6-*f* complex, ATP is synthesized. Because in this process high energy electrons released from 'P-680' do not return to 'P-680' and ATP (1 molecules) is formed, this is called Noncyclic photophosphorylation. ATP is synthesized at only one step.

This non-cyclic photophosphorylation is also known as Z-scheme (because of shape of path of electron-flow) and this was given by Hill and Bendall (1960). Non-cyclic photophosphorylation or Z-scheme is inhibited by CMU and DCMU.

(DCMU is a herbicide which kills the weed by inhibiting CO_2 fixation as it is a strong inhibitor of PS-II).

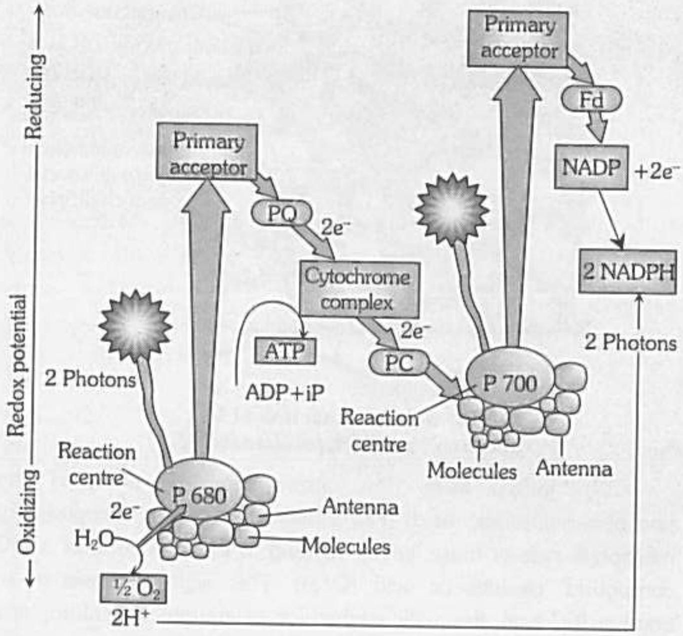


Fig : 4.3-4 Non cyclic photophosphorylation (Z-scheme)

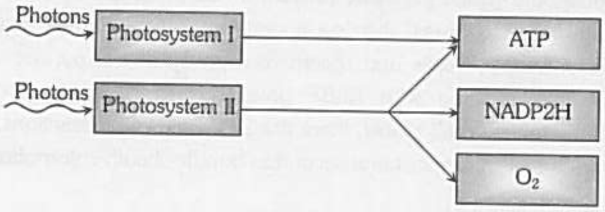


Fig : 4.3-5 Final products of light reactions

Pseudocyclic photophosphorylation : Arnon and his coworker (1954) demonstrated yet another kind of photophosphorylation. They observed that even in absence of CO_2 and NADP, if chlorophyll molecules are illuminated, it can produce ATP from ADP and iP (Inorganic phosphate) in presence of FMN or vit. K and oxygen. The process is thus very simple and requires no net chemical change for the formation of ATP and water. Arnon called this oxygen dependent FMN catalysed photophosphorylation or pseudocyclic photophosphorylation which involves the reduction of FMN with the production of oxygen. FMN is an auto-oxidisable hydrogen acceptor with the effect that the reduced FMN is reoxidised by oxygen. Thus the process can continue repeatedly to produce ATP.

Since this process can be continuously self repeated, it appears that a single molecule of water should be sufficient to operate pseudocyclic photophosphorylation to meet the requirement of ATP.

$$FMN + H_2O \xrightleftharpoons[\text{ADP+iP} \rightarrow \text{ATP}]{\text{Illuminated chloroplast}} FMNH_2 + \frac{1}{2} O_2$$

Dark phase : The pathway by which all photosynthetic eukaryotic organisms ultimately incorporate CO_2 into carbohydrate is known as carbon fixation or photosynthetic carbon reduction (PCR) cycle or dark reactions.

The dark reactions are sensitive to temperature changes, but are independent of light hence it is called dark reaction, however it depends upon the products of light reaction of photosynthesis, *i.e.*, NADP .2H and ATP.

The carbon dioxide fixation takes place in the stroma of chloroplasts because it has enzymes essential for fixation of CO_2 and synthesis of sugar.

The techniques used for studying different steps were Radioactive tracer technique using ^{14}C (Half life – 5720 years), Chromatography and Autoradiography and the material used was *Chlorella* (Cloacal alga) and *Scenedesmus* (these are microscopic, unicellular algae and can be easily maintained in laboratory).

The assimilation and reduction of CO_2 takes place in this reaction by which carbohydrate is synthesized through following three pathways :

(1) **Calvin cycle :** Calvin and Benson discovered the path of carbon in this process. This is known as C_3 cycle because CO_2 reduction is cyclic process and first stable product in this cycle is a 3-C compound (*i.e.*, 3-Phosphoglyceric acid or 3-PGA).

Calvin cycle is divided into three distinct phases : Carboxylation, Glycolytic reversal, regeneration of RuBP.

In this cycle, CO_2 acceptor molecule is RuBP or RuDP (*i.e.*, Ribulose 1, 5-biphosphate or Ribulose 1, 5-diphosphate). There occurs covalent bonding of CO_2 to RuBP and the enzyme catalyzing this reaction is RuBP-carboxylase/oxygenase (Rubisco).

As calvin cycle takes in only one carbon (as CO_2) at a time, so it takes six turns of the cycle to produce a net gain of six carbons (*i.e.*, hexose or glucose).

In this cycle, for formation of one mole of hexose sugar (Glucose), 18 ATP and 12 $NADPH_2$ are used.

The plants in which this pathway of CO_2 reduction occurs, are called C-3 plants.

About 85% of plant species are C-3 plants, including cereals (*e.g.*, barley, rice, oat, wheat), groundnut, sugarbeet, cotton, tobacco, spinach, soybean most trees and lawn grasses etc.

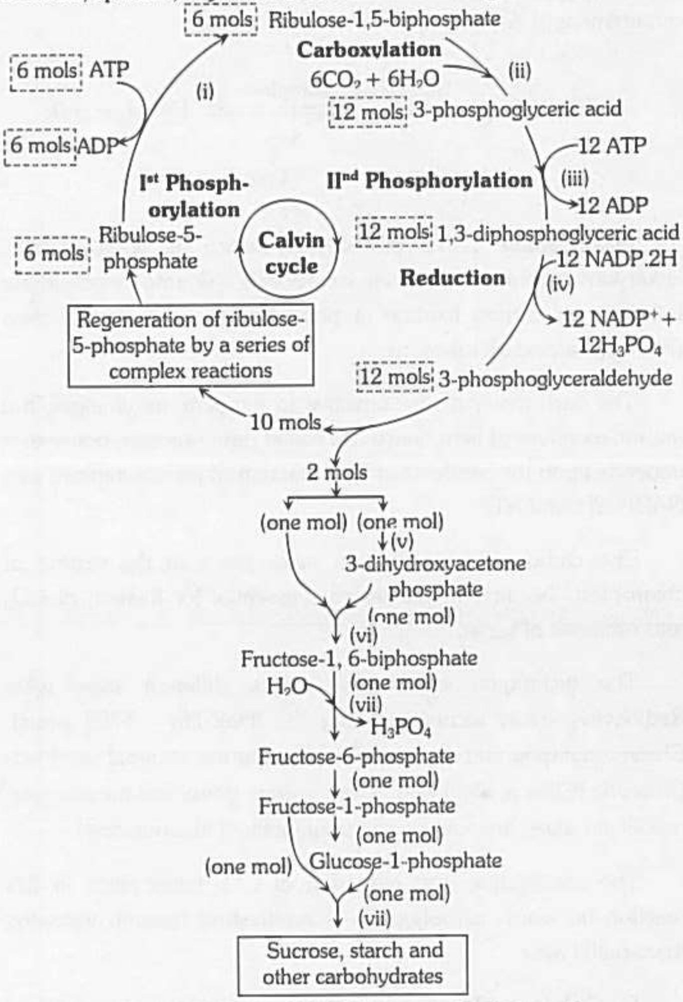


Fig : 4.3-6 Simplified diagram of Calvin cycle

Enzyme : (i) Phosphopentokinase, (ii) Carboxydismutase, (iii) Phosphoglyceric kinase, (iv) Triose phosphate dehydrogenase, (v) Phosphotriose isomerase, (vi) Aldolase, (vii) Phosphatase

(2) **Hatch and Slack cycle (C_4 cycle) :** Kortschak and Hart supplied CO_2 to the leaves of sugarcane, they found that the first stable product is a four carbon (C_4) compound oxalo acetic acid instead of 3-carbon atom compound. The detailed study of this cycle has introduced by M.D. Hatch and C.R. Slack (1966). So it is called as "Hatch and Slack cycle". The stable product in C_4 plant is a dicarboxylic substance. Hence it is called dicarboxylic acid cycle or DCA-cycle. C_4 plants are true xerophytic plants. They are adapted for hot and dry climate.

The important C_4 plants are sugarcane, maize, Sorghum, *Cyperus rotundus, Digitaria brownii, Amaranthus*, etc. These plants have "Kranz" (German term meaning halo or wreath) type of leaf anatomy. The vascular bundles, in C_4 leaves are surrounded by a layer of bundle sheath cells that contain large number of chloroplasts. The chloroplasts in C_4 leaves are dimorphic (Two morphologically distinct types). The chloroplasts of bundle sheath cells are larger in size and arranged centripetally. They contain starch grains but lack grana. The mesophyll cells, on the other hand, contain normal types of chloroplasts. Mesophyll and bundle sheath cells are connected by plasmodesmata. The mesophyll cells perform C_4 cycle and the cells of bundle sheath perform C_3 cycle.

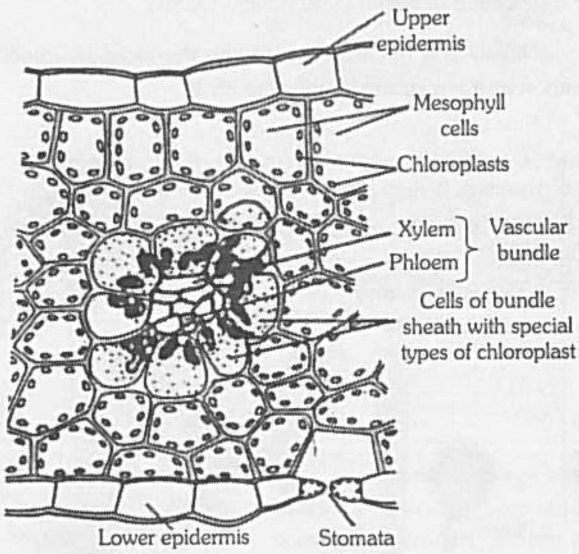


Fig : 4.3-7 Cross section of leaf showing "kranz" type of anatomy

CO_2 taken from the atmosphere is accepted by phosphoenolpyruvic acid (PEP) present in the chloroplasts of mesophyll cells of these leaves, leading to the formation of a 4-C compound, oxaloacetic acid (OAA). This acid is converted to another 4-C acid, the malic acid which enters into the chloroplasts of bundle sheath cells and there undergoes oxidative decarboxylation yielding pyruvic acid (a 3-C compound) and CO_2. CO_2 released in bundle sheath cells reacts with Ribulose-1,5-biphosphate (RuBP) already present in the chloroplasts of bundle sheath cells and thus Calvin cycle starts from here. Pyruvic acid re-enters mesophyll cells and regenerates phosphoenol pyruvic acid. CO_2 after reacting with RuBP gives rise to sugars and other carbohydrates. In C_4 plants, there are 2 carboxylation reactions, first in mesophyll chloroplast and second in bundle sheath chloroplast.

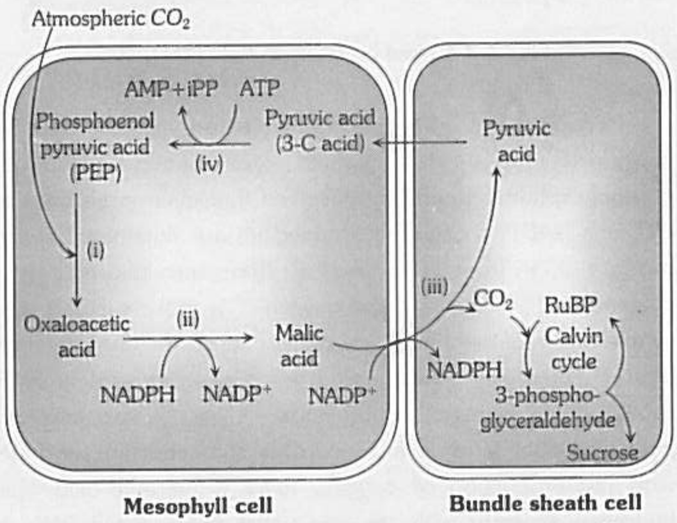


Fig : 4.3-8 Hatch-slack's pathway (cycle) Enzymes : (i) Phosphoenol pyruvate carboxylase, (ii) Malate dehydrogenase, (iii) Decarboxylase, (iv) Pyruvate orthophosphate dikinase

C_4 plants are better photosynthesizers. There is no photorespiration in these plants. In C_4 plants, for formation of one molecule of hexose (glucose) 30 ATP and 12 $NADPH_2$ are required.

Characteristics of C_4 cycle

(1) C_4 species have greater rate of CO_2 assimilation than C_3 species. This is on account of the fact that

(i) PEP carboxylase has great affinity for CO_2.

(ii) C_4 plants show little photorespiration as compared to C_3 plants, resulting in higher production of dry matter.

(2) C_4 plants are more adapted to environmental stresses than C_3 plants.

(3) CO_2 fixation by C_4 plants requires more ATP than that by C_3 plants. This additional ATP is needed for conversion of pyruvic acid to phosphoenol pyruvic acid and its transport.

(4) CO_2 acceptor molecule in C_4 plants is PEP. Further, PEP-carboxylase (PEPCO) is the key enzyme (RuBP-carboxylase enzyme is negligible or absent in mesophyll chloroplast, but is present in bundle sheath chloroplast).

(3) **Crassulacean acid metabolism (CAM)** : This dark CO_2 fixation pathway proposed by Ting (1971). It operates in succulent or fleshy plants *e.g.*, *Cactus*, *Sedum*, *Kalanchoe*, *Opuntia*, *Agave*, Orchid, Pineapple and *Bryophyllum* helping them to continue photosynthesis under extremely dry condition.

The stomata of succulent plants remain closed during day and open during night to avoid water loss (Scotoactive stomata). They store CO_2 during night in the form of malic acid in presence of enzyme PEP carboxylase. The CO_2 stored during night is used in Calvin cycle during day time. Succulents refix CO_2 released during respiration and use it during photosynthesis.

This diurnal change in acidity was first discovered in crassulacean plants *e.g.*, *Bryophyllum*. So it is called as crassulacean acid metabolism.

Formation of malic acid during dark is called acidification or phase-I. Release of CO_2 for actual photosynthesis during day is called deacidification or phase-II.

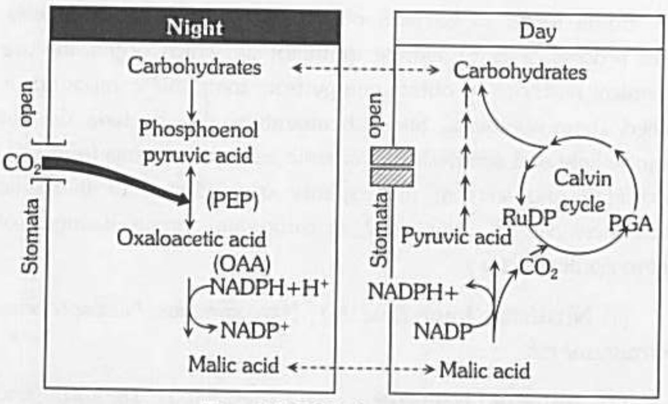


Fig : 4.3-9 Mechanism of CAM

Characteristics of CAM pathway

(1) There is decrease in *pH* during the night and increase in *pH* during the day.

(2) CAM plants have enzymes of both C_3 and C_4 cycle in mesophyll cells. This metabolism enable CAM plants to survive under xeric habitats. These plants have also the capability of fixing the CO_2 lost in respiration.

(3) Malic acid is stored in the vacuoles during the night which is decarboxylated to release CO_2 during the day.

CO_2 compensation point

In photosynthesis, CO_2 is utilized in presence of light to release O_2 whereas in respiration, O_2 is taken and CO_2 is released. If light factor is saturating, there will be certain CO_2 concentration at which rate of photosynthesis is just equal to rate of respiration or photosynthesis just compensates respiration or apparent photosynthesis is nil. It is called CO_2 compensation point.

❑ CO_2 compensation point is very low in C_4 plants, *i.e*, 0 to 5 ppm whereas high CO_2 compensation point is found in C_3 plants, *i.e.*, 25 to 100 ppm.

Photorespiration or CO_2 Cycle

Decker and Tio (1959) reported that light induces oxidation of photosynthetic intermediates with the help of oxygen in tobacco. It is called as photorespiration. The photorespiration is defined by Krotkov (1963) as an extra input of O_2 and extra release of CO_2 by green plants is light.

Photorespiration is the uptake of O_2 and release of CO_2 in light and results from the biosynthesis of glycolate in chloroplasts and subsequent metabolism of glycolate acid in the same leaf cell. Biochemical mechanism for photorespiration is also called glycolate metabolism.

Loss of energy occurs during this process. The process of photorespiration involves the involvement of chloroplasts, peroxysomes and mitochondria. RuBP carboxylase also catalyses another reaction which interferes with the successful functioning of Calvin cycle.

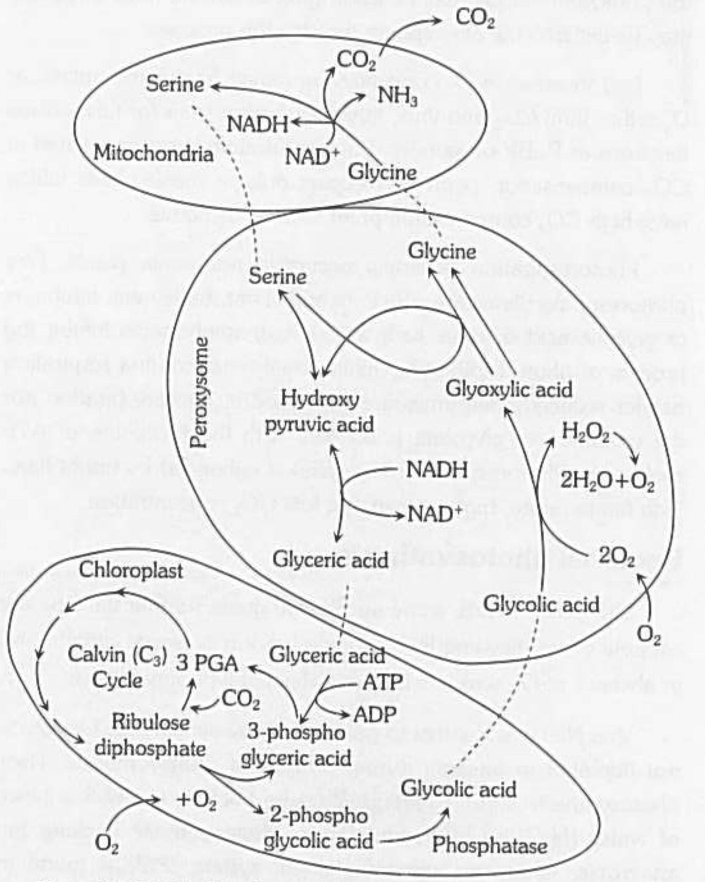


Fig : 4.3-10 The biochemical pathway of photorespiration

Biochemical mechanism

(1) Ribulose-1, 5-biphosphate $\xrightarrow{O_2}$

2 Phosphoglycolic acid +3 Phosphoglyceric acid

(2) 2 Phosphoglycolic acid + H_2O $\xrightarrow{\text{Phosphatase}}$

Glycolic acid + Phosphoric acid.

(3) Glycolic acid + O_2 $\xrightarrow[\text{oxidase}]{\text{Glycolic acid}}$ Glyoxylic acid + H_2O_2

$2H_2O_2 \xrightarrow{\text{Catalase}} 2H_2O + O_2$

(4) Glyoxylic acid + Glutamic acid $\xrightarrow[\text{transaminase}]{\text{Glutamate-glyoxylate}}$

Glycine + α-keto glutaric acid

(5) 2 Glycine + H_2O + NAD^+ $\longrightarrow$

Serine + CO_2 + NH_3 + $NADH$

(6) Serine + Glyoxylic acid $\longrightarrow$ Hydroxypyruvic acid

Glycine + Hydroxypyruvic acid $\longrightarrow$ Glyceric acid

(7) Glyceric acid + ATP $\rightarrow$ 3 phosphoglyceric acid

+ ADP + phosphate

Importance of photorespiration : Photorespiration is quite different from respiration as no ATP or NADH are produced. Moreover, the process is harmful to plants because as much as half the photosynthetically fixed carbon dioxide (in the form of RuBP) may be lost into the atmosphere through this process.

Any increase in O_2 concentration would favour the uptake of O_2 rather than CO_2 and thus, inhibit photosynthesis for this rubisco functions as RuBP oxygenase. Photorespiration is closely related to CO_2 compensation point and occurs only in those plants which have high CO_2 compensation point such as C_3 plants.

Photorespiration generally occurs in temperate plants. Few photorespiring plants are : Rice, bean, wheat, barley etc. Inhibitors of glycolic acid oxidase such as hydroxy sulphonates inhibit the process of photorespiration. Unlike usual mitochondria respiration neither reduced coenzymes are generated in photorespiration nor the oxidation of glycolate is coupled with the formation of ATP molecules. Photorespiration (C_2 cycle) is enhanced by bright light, high temperature, high oxygen and low CO_2 concentration.

Bacterial photosynthesis

Like green plants, some purple and green sulphur bacteria are capable of synthesizing their organic food in presence of light and in absence of O_2, which is known as bacterial photosynthesis.

Van Niel was the first to point out these similarities. Oxygen is not liberated in bacteria during process of photosynthesis. Their photosynthesis is non-oxygenic. Because bacteria use H_2S in place of water (H_2O) as hydrogen donor. Photosynthetic bacteria are anaerobic. Only one type of pigment system (PSI) is found in bacteria except cyanobacteria which possess both PSI and PSII.

Bacteria has two type of photosynthetic pigments. Bacteriochlorophyll and Bacterioviridin. Bacteriochlorophyll differs from Chl. *a* in having one pyrrol ring with two hydrogen.

The photosynthetic bacteria fall under three categories

(1) **Green sulphur bacteria :** It contains chlorobium chlorophyll, which absorb 720-750*nm* (far red light) of wavelength of light. *e.g., Chlorobium.*

(2) **Purple sulphur bacteria :** *e.g., Chromatium.*

(3) **Purple non-sulphur bacteria :** *e.g., Rhodospirillum, Rhodopseudomonas.*

Characteristics of bacterial photosynthesis are :

(1) No definite chloroplasts but contain simple structures having pigments called chromatophores (term coined by Schmitz).

(2) Contain chlorobium chlorophyll or bacterio-chlorophyll.

(3) Use longer wavelengths of light (720-950*nm*).

(4) No utilization of H_2O (but use H_2S or other reduced organic and inorganic substances).

(5) No evolution of O_2.

(6) Photoreductant is $NADH_2$ (Not $NADPH_2$).

(7) Only one photoact and hence one pigment system and thus one reaction centre, *i.e.,* P_{890}.

(8) Cyclic photophosphorylation is dominant.

(9) It occurs in presence of light and in absence of O_2.

Chemosynthesis

Some forms of bacteria obtain energy by chemosynthesis. This process of carbohydrate formation in which organisms use chemical reactions to obtain energy from inorganic compounds is called chemosynthesis. Such chemoautotrophic bacteria do not require light and synthesize all organic cell requirements from CO_2 and H_2O and salts at the expense of oxidation of inorganic substances like (H_2, NO_3^-, SO_4 or carbonate). Some examples of chemosynthesis are :

(1) **Nitrifying bacteria :** *e.g., Nitrosomonas, Nitrosococcus, Nitrobacter* etc.

(2) **Sulphur bacteria :** *e.g., Beggiatoa, Thiothrix* and *Thiobacillus.*

(3) **Iron bacteria :** *e.g., Ferrobacillus, Leptothrix* and *Cladothrix.*

(4) **Hydrogen bacteria :** *e.g., Bacillus pentotrophus*

(5) **Carbon bacteria :** *e.g., Carboxydomonas, Bacillus oligocarbophilus.*

Factors affecting photosynthesis

Blackman's law of limiting factors

F.F. Blackman (1905) proposed the law of limiting factors according to which 'when process is conditioned to its rapidity by a number of factors, the rate of process is limited by the pace of the slowest factor'. CO_2 is usually a limiting factor in photosynthesis under field conditions particularly on clear summer days under adequate water supply.

Blackman's law of limiting factor is modification of Liebig's law of minimum, which states that rate of process controlled by several factors is only as rapid as the slowest factor permits. Theory of three cardinal points was given by Sachs in 1860. According to this concept, there is minimum, optimum and maximum for each factor. For every factor, there is a minimum value when photosynthesis starts, an optimum value showing highest rate and a maximum value, above which photosynthesis fails to take place.

Factors : The rate of photosynthetic process is affected by several external (Environmental) and internal factors.

External factors

(1) **Light :** The ultimate source of light for photosynthesis in green plants is solar radiation, which moves in the form of electromagnetic waves. Out of the total solar energy reaching to the earth about 2% is used in photosynthesis and about 10% is used in other metabolic activities. Light varies in intensity, quality (Wavelength) and duration. The effect of light on photosynthesis can be studied under these three headings.

(i) **Light intensity :** The total light perceived by a plant depends on its general form (*viz.*, height, size of leaves, etc.) and arrangement of leaves. Of the total light falling on a leaf, about 80% is absorbed, 10% is reflected and 10% is transmitted.

In general, rate of photosynthesis is more in intense light than diffused light. (Upto 10% light is utilized in sugarcane, *i.e.*, Most efficient converter).

Another photosynthetic superstar of field growing plants is *Oenothera claviformis* (Winter evening-primrose), which utilizes about 8% light.

However, this light intensity varies from plant to plant, *e.g.*, more in heliophytes (sun loving plants) and less in sciophytes (shade loving plants). For a complete plant, rate of photosynthesis increases with increase in light intensity, except very high light intensity where 'Solarization' phenomenon occurs, *i.e.*, photo-oxidation of different cellular components including chlorophyll occurs.

It also affects the opening and closing of stomata thereby affecting the gaseous exchange. The value of light saturation at which further increase is not accompanied by an increase in CO_2 uptake is called light saturation point.

(ii) **Light quality :** Photosynthetic pigments absorb visible part of the radiation *i.e.*, $380m\mu$ to $760m\mu$. For example, chlorophyll absorbs blue and red light. Usually plants show high rate of photosynthesis in the blue and red light. Maximum photosynthesis has been observed in red light than in blue light. The green light has minimum effect. On the other hand, red algae shows maximum photosynthesis in green light and brown algae in blue light.

(iii) **Duration of light :** Longer duration of light period favours photosynthesis. Generally, if the plants get 10 to 12*hrs* light per day it favours good photosynthesis. Plants can actively exhibit photosynthesis under continuous light without being damaged. Rate of photosynthesis is independent of duration of light.

(2) **Temperature :** The optimum temperature for photosynthesis is 20 to 35°C. If the temperature is increased too high, the rate of photosynthesis is also reduced by time factor which is due to denaturation of enzymes involved in the process. Photosynthesis occurs in some conifers at high altitudes at – 35°C. Some algae in hot springs can undergo photosynthesis even at 75°C.

(3) **Carbon dioxide :** Carbon dioxide present in the atmosphere is about 0.032% by volume and it is really a low concentration which acts as limiting factor in nature. If we increase the amount of CO_2 under laboratory conditions and if the light and temperature are not the limiting factors, the rate of photosynthesis increases. This increase is observed upto 1% of CO_2 concentration. At the same time very high concentration of CO_2 becomes toxic to plants and inhibits photosynthesis.

(4) **Water :** Water is an essential raw material in photosynthesis. This rarely, acts as a limiting factor because less than 1% of the water absorbed by a plant is used in photosynthesis. However, lowering of photosynthesis has been observed if the plants are inadequately supplied with water.

(5) **Oxygen :** Excess of O_2 may become inhibitory for the process. Enhanced supply of O_2 increases the rate of respiration simultaneously decreasing the rate of photosynthesis by the common intermediate substances. The concentration for oxygen in the atmosphere is about 21% by volume and it seldom fluctuates. O_2 is not a limiting factor of photosynthesis. An increase in oxygen concentration decreases photosynthesis and the phenomenon is called Warburg effect. (Reported by German scientist Warburg (1920) in *Chlorella* algae).

This is due to competitive inhibition of RuBP-carboxylase by increased O_2 levels, *i.e.*, O_2 competes for active sites of RuBP-carboxylase enzyme with CO_2. The explanation of this problem lies in the phenomenon of photorespiration. If the amount of oxygen in the atmosphere decreases then photosynthesis will increase in C_3 cycle and no change in C_4 cycle.

(6) **Pollutants and Inhibitors :** The oxides of nitrogen and hydrocarbons present in smoke react to form peroxyacetyl nitrate (PAN) and ozone. PAN is known to inhibit Hill reaction. Diquat and Paraquat (Commonly called as Viologens) block the transfer of electrons between Q and PQ in PS. II. Other inhibitors of photosynthesis are monouron or CMU (Chlorophenyl dimethyl urea) diuron or DCMU (Dichlorophenyl dimethyl urea), bromocil and atrazine etc. Which have the same mechanism of action as that of viologens.

At low light intensities potassium cyanide appears to have no inhibiting effect on photosynthesis.

(7) **Minerals :** Presence of Mn^{++} and Cl^- is essential for smooth operation of light reactions (Photolysis of water/evolution of oxygen) Mg^{++}, Cu^{++} and Fe^{++} ions are important for synthesis of chlorophyll.

Internal factors

(1) **Protoplasmic factors :** There is some unknown factor which affects the rate of photosynthesis.

These factors affect the dark reactions. The decline in the rate of photosynthesis at temperature above 30°C or at strong light intensities in many plants suggests the enzymatic nature of this unknown factor.

(2) **Chlorophyll content :** Chlorophyll is an essential internal factor for photosynthesis. The amount of CO_2 fixed by a gram of chlorophyll in an hour is called photosynthetic number or assimilation number. It is usually constant for a plant species but rarely it varies. The assimilation number of variegated variety of a species was found to be higher than the green leaves variety.

(3) **Accumulation of end products :** Accumulation of food in the chloroplasts reduces the rate of photosynthesis.

(4) **Structure of leaves :** The amount of CO_2 that reaches the chloroplast depends on structural features of the leaves like the size, position and behaviour of the stomata and the amount of intercellular spaces. Some other characters like thickness of cuticle, epidermis, presence of epidermal hairs, amount of mesophyll tissue, etc., influence the intensity and quality of light reaching in the chloroplast.

Tips & Tricks

- Photosynthetic materials : 264 gm of CO_2 and 216 *gm* of water give rise to 108 *gm* of water, 192 *gm* of O_2 and 180 *gm* of glucose.
- Rubisco : Rubisco constitutes 16% of chloroplast protein. It is the most abundant protein on this planet.
- Willmott's bubbler is used to measure rate of O_2 evolution or rate of photosynthesis.
- T.W. Engelmann (1882) experimentally verified that in monochromatic lights, photosynthesis is maximum in red light.
- NADP (Nicotinamide adenine dinucleotide phosphate) was earlier called as TPN (Triphosphopyridine nucleotide),
- In green plants the hydrogen acceptor is NADP, but in bacteria it is NAD.
- No Emerson effect is seen in bacteria.
- Cytochromes : The terms was coined by Keilin (1925) though the biochemicals were discovered by Mac Munn (1866).
- Cytochrome proteins serving as electron carriers in respiration, photosynthesis and other oxidative reduction reactions.
- Intensity of light can be measured by Luxmeter.
- Isolated chlorophyll 'a' in pure form emits red colour. It is called fluoresence.
- In angiosperms, synthesis of chlorophyll occurs in presence of light.
- The precursor of chlorophyll is chlorophyllide.
- Chlorophyll term was coined by Pelletier and Coventou (1818) who also discovered the pigment.
- *Hydrilla* plant is used in an experiment commonly performed in laboratory in demonstrate evolution of O_2 in photosynthesis.

Ordinary Thinking

Objective Questions

History of photosynthesis

1. The law of limiting factor for photosynthesis was enunciated by **[NCERT; CMC Vellore 1994; CBSE PMT 1996; CPMT 2001; Manipal 2001, 05; KCET 2004; BHU 2006]**

(a) Blackman (b) Hill
(c) Ruben (d) Kalmen

2. 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

3. Two pigment system theory of photosynthesis was proposed by or Concept of evidence for existence of two photosystems in photosynthesis was given by **[CBSE PMT 1994; Kerala CET 2003; KCET 2003]**

(a) Hill (b) Blackman
(c) Emerson (d) Arnon

4. Who received the Nobel Prize for working out the early carbon pathway of photosynthesis **[AIEEE Pharmacy 2003]**

(a) Calvin (b) Krebs
(c) Khorana (d) Watson

5. Which of the following technique was used by Calvin in determining carbon pathway **[MP PMT 1992]**

(a) Chromatography (b) Electrophorosis
(c) Spectrophotometery (d) Histochemistry

6. The process of photophosphorylation was discovered by **[Pb. PMT 1999, 2000]**

(a) Calvin (b) Arnon
(c) Priestley (d) Warburg

7. 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

8. 'Photosynthesis is the conversion of light energy within a plant' was first stated by

(a) Willstatter and Stoll (b) Mayor and Anderson
(c) Benson and Calvin (d) Robert Mayer

9. '*Thylakoid*' name was given by **[RPMT 1995]**

(a) Arnon (b) Park and Biggins
(c) Park and Fortan (d) Manke

10. The significance of light and chlorophyll in photosynthesis was discovered by **[Bihar MDAT 1995]**

(a) Priestley (b) Ingenhousz
(c) Englemann (d) Blackman

11. "The amount of CO_2 absorbed and O_2 released during photosynthesis are in equal volumes" was proved by

(a) Englemann (b) Robert Mayer
(c) Priestley (d) Bousingault

12. The first important biological investigation which led to the conclusion that plant makes its substance from water and not from soil was carried out by
(a) Lamarck (b) De Vries
(c) Van Helmont (d) Darwin

13. Early studies on the pathway of CO_2 fixation in plants were made during 1940s in
(a) Unicellular green algae by Calvin
(b) Isolated chloroplast of spinach by Hill
(c) Mesophyll cells of variegated leaves by Arnon
(d) Bundle sheath cells of maize by Hatch and Slack

14. Who proposed the cycle of events leading to the fixation of CO_2 in mesophyll and its reduction in bundle sheath
(a) Emerson (b) Melvin Calvin
(c) Hatch and Slack (d) Hill and Bendall

15. The scientist, who proved that bacteria use H_2S gas and CO_2 to synthesize carbohydrate, is **[NCERT]**
(a) Van Niel (b) Ruben
(c) Jean Senebier (d) Julius Robert Mayer

16. Emerson's enhancement effect and Red drop have been instrumental in the discovery of **[NEET (Phase-I) 2016]**
(a) Photophosphorylation and non-cyclic electron transport
(b) Two photosystems operating simultaneously
(c) Photophosphorylation and cyclic electron transport
(d) Oxidative phosphorylation

Experiments

1. What plant is used in an experiment commonly performed in laboratory in demonstrate evolution of oxygen in photosynthesis **[RPMT 1997]**
(a) Sunflower (b) *Hydrilla*
(c) Croton (d) Balsam

2. Engelmann's experiment with *Spirogyra* demonstrated that **[BVP 2003]**
(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

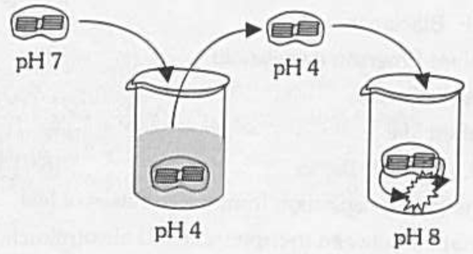
3. Two plants A and B are supplied with CO_2 with H_2O^{18} and CO_2^{18} with H_2O respectively which of the following plant releases O^{18} type oxygen in photosynthesis **[CPMT 2000]**
(a) A plant (b) B plant
(c) Both (a) and (b) (d) First (a) and then (b)

4. Isotopes popularly known to have been used in the study of photosynthesis are **[MH CET 2007]**

Or

Which of the following isotope of carbon was used by Calvin to trace the path of carbon in photosynthesis **[CPMT 1995]**
(a) C^{14} and O^{18} (b) C^{11} and C^{32}
(c) C^{16} and N^{15} (d) P^{32} and C^{15}

5. 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 were 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 **[NCERT]**



(a) $C_6H_{12}O_6$ (b) G3P
(c) NAD (d) ATP

6. Path of carbon in photosynthesis was found by using **[Kerala CET 2002]**
(a) Centrifugation (b) Radio isotopes
(c) Fractionation (d) Chromatography

7. Persons who received Nobel Prizes for their work with green plants are
(a) Calvin and Waston (b) Calvin and Borlang
(c) Beadle and Tatum (d) Flemming and Waksman

8. Which of the following with respect to early experiments of photosynthesis is wrongly matched **[Kerala PMT 2012]**
(a) Joseph Priestley – Showed that plants release O_2
(b) Jan Ingenhousz – Showed that sunlight is essential for photosynthesis
(c) Julius von Sachs – Proved that plants produce glucose when they grow
(d) T.W. Engelmann – Showed that the green substance is located within special bodies in plant
(e) Cornelius van Net – Showed that hydrogen reduces CO_2 to carbohydrates

9. 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 **[BHU 1992]**
(a) O_2^{18} (b) $C^{14}O_2$
(c) P^{36} (d) X-rays

10. Algae used by Calvin and associates for photosynthetic research is **[RPMT 2002]**

Or

The experimental material that has largely been responsible for making rapid advances in research on photosynthesis is **[RPMT 2002]**

Or

Warburg studied his effect on
(a) *Chlorella* (b) *Chlamydomonas*
(c) *Volvox* (d) All the above

11. The oxygen produced during photosynthesis comes from photolysis of water was first time proved by **[MP PMT 1995]**
(a) Ruben and Kamen (b) Robert Mayer
(c) Malvin Calvin (d) Blackman

12. The first experiment on photosynthesis in flashing light were carried out by **[AFMC 2006]**
(a) F. F. Blackman
(b) Robert Emerson and Arnold
(c) Melvin Calvin
(d) Robert Hill

13. Moll's experiment shows **[KCET 2001]**
(a) Unequal transpiration from two surfaces of leaf
(b) Relation between transpiration and absorption
(c) CO_2 is required for photosynthesis
(d) Chlorophyll is essential for photosynthesis

Photosynthetic apparatus

1. The plants growing in dark show yellowing in leaves and elongated internodes, this condition is called as **[BHU 1999]**
(a) Etiolation (b) Chlorosis
(c) Dechlorosis (d) Dark effect

2. The most vital process for the existence of life on earth is **[KCET 1994]**
(a) Communication in animals
(b) Photosynthesis by plants
(c) Reproduction in plants and animals
(d) Respiration in animals

3. 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*

[Kerala PMT 2007]
(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

4. How many molecules of water are needed by a green plant to produce one molecule of hexose/ reduce 6 molecules of CO_2
(a) 6 (b) 12
(c) 24 (d) One only

5. The first event in photosynthesis is **[JIPMER 2002; CBSE PMT 2000; AIEEE Pharmacy 2004]**
(a) Synthesis of ATP
(b) Photoexcitation of chlorophyll and ejection of electron
(c) Photolysis of water
(d) Release of oxygen

6. Which of the following represents the correct molecular formula of chlorophyll-*b* **[RPMT 2005]**
(a) $C_{55}H_{72}O_6N_4Mg$ (b) $C_{55}H_{72}O_5N_4Mg$
(c) $C_{55}H_{72}O_4N_4Mg$ (d) $C_{55}H_{70}O_5N_4Mg$
(e) $C_{55}H_{70}O_6N_4Mg$

7. Solar energy is converted into *ATP* in

Or

Light energy is converted into chemical energy in the presence of **[MP PMT 1994]**
(a) Mitochondria (b) Chloroplasts
(c) Ribosomes (d) Peroxisomes

8. Which process is related with photosynthesis **[CPMT 1998]**
(a) Phosphorylation (b) Translation
(c) Transcription (d) None of these

9. Which of the following equation can be more appropriate for photosynthesis **[NCERT; KCET 1994; Kerala PMT 2004, 06]**
(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

10. Quantasomes are found in **[RPMT 1995]**
(a) Surface of cristae
(b) Surface of plasma membrane
(c) Surface of nuclear membrane
(d) Surface of thylakoids

11. The full expansion of *NADP* is **[RPMT 1997]**
(a) Nicotinamide adenine diphosphate
(b) Nicotinamide adenosine diphosphate
(c) Nicotinamide adenine dinucleotide phosphate
(d) Nicotinamide adenosine dinucleotide phosphate

12. Make suitable pair
(A) Emerson effect (a) C_4 cycle
(B) Hill reaction (b) Photolysis
(C) Calvin's cycle (c) C_3 cycle
(D) Hatch and Slack cycle (d) Photosystem–I and II
[RPMT 1997]
(a) Aa, Bb, Cc, Dd (b) Aa, Bc, Cd, Db
(c) Ac, Bd, Ca, Db (d) Ad, Bb, Cc, Da

13. Suspension of isolated thylakoids in culture medium containing CO_2 and H_2O does not produce hexose due to absence of which of the following **[DPMT 2004]**
(a) ATP (b) Enzyme
(c) Proteins (d) Hill reagent

14. 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

[RPMT 1995; MP PMT 2000; Kerala PMT 2004]

(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

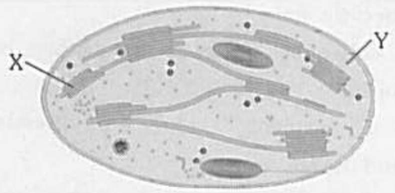
15. 85–90% of all photosynthesis of the world is carried out by **[AMU (Med.) 2009]**

Or

The maximum evolution of oxygen is by greatest producers of organic matter

(a) Shrubs
(b) Herbs
(c) Oceanic algae/Phytoplanktons
(d) Trees with large branches

16. See the following diagram and identify X and Y with their functions **[NCERT]**



	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

17. In photosynthesis, energy from light reaction to dark reaction is transferred in the form of **[CBSE PMT 2002]**

(a) ADP (b) ATP
(c) RUDP (d) Chlorophyll

18. The synthesis of ATP in photosynthesis and respiration is essentially an oxidation-reduction process involving removal of energy from **[CBSE PMT 1992; BHU 1994]**

Or

Which one is always transferred in redox reaction **[Odisha JEE 2009]**

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

19. In photosynthesis, plants **[AFMC 2003; MP PMT 2004]**

(a) Absorb O_2 and release CO_2
(b) Absorb CO_2 and release O_2
(c) Absorb NH_3 and release N_2
(d) Absorb N_2 and release NH_3

20. Wavelength of green light is

(a) 400 – 450 $m\mu$ (b) 500 – 550 $m\mu$
(c) 660 – 720 $m\mu$ (d) 720 – 800 $m\mu$

21. 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

22. Ribulose diphosphate carboxylase oxygenase is located in

(a) Mitochondria (b) Chloroplasts
(c) Peroxisomes (d) Golgi bodies

23. The percentage of light energy utilized for photosynthesis by higher plants is **[Odisha JEE 2008]**

(a) 100% (b) 50 %
(c) 10% (d) 1 to 2%

24. During photosynthesis **[BHU 1995; CPMT 1998, 2003; Pb. PMT 2000, 03; RPMT 2005]**

(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 get reduced, water get oxidised and ATP is formed

25. Intensity of light can be measured by

(a) Luxmeter (b) Wilmott's bubbler
(c) Ganong's potometer (d) Farmer's potometer

26. Assimilatory power refers to **[AFMC 1994]**

(a) Generation of ATP and $NADPH_2$
(b) Reduction of CO_2
(c) Splitting of water
(d) Disintegration of plastids

27. Grana refers to

(a) Stacks of thylakoids in plastids of higher plants
(b) A constant in quantum equation
(c) Glycolysis of glucose
(d) Bye product of photosynthesis

28. Intact chloroplast from green leaves can be isolated by

(a) Acetone (b) Ethanol
(c) Alcohol (d) Sugar solution

29. Dimorphic chloroplasts are present in **[MHCET 2002; WB JEE 2008, 10]**

(a) Sugarcane(C_4) (b) Cotton
(c) Pea (d) Mango

30. Phenomenon which converts light energy into chemical energy is **[AFMC 2005]**

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

31. For the process of photosynthesis all except one of the following items are essential. Point out the exception

(a) Water, minerals
(b) Light, chlorophyll
(c) CO_2, optimum temperature
(d) Oxygen, sucrose

32. Plants are known as purifiers of air due to process of **[MP PMT 1996; WB JEE 2008]**
(a) Respiration (b) Photosynthesis
(c) Transpiration (d) Desiccation

33. In the overall process of photosynthesis, the number of CO_2, water, sugar and O_2 molecules utilized and produced is **[AMU (Med.) 2012]**
(a) 12 (b) 13
(c) 19 (d) 31

34. CO_2 is formed in all of the following except
(a) Burning of sugar (b) Respiration in plants
(c) Photosynthesis by plants (d) On heating of limestone

35. Quantasomes contain
(a) 200 chlorophyll molecules (b) 230 chlorophyll molecules
(c) 250 chlorophyll molecules (d) 300 chlorophyll molecules

36. Which one of the following is energy currency of the cell or The common immediate source of energy in cellular activity is **[MH CET 2000]**
(a) Phosphate (b) ATP
(c) ADP (d) AMP

37. 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

Light reaction/Pigments

1. Manganese and Chlorine is required in **[NCERT; BHU 2005; CBSE PMT 2009; Kerala PMT 2009, 10; CBSE PMT (Mains) 2011; CBSE PMT (Pre.) 2012; AIPMT 2015]**
(a) Nucleic acid synthesis
(b) Plant cell wall formation
(c) Photolysis of water during photosynthesis
(d) Chlorophyll synthesis

2. Stroma in the chloroplasts of higher plant contains **[CBSE PMT 2009; AIPMT 2015]**
(a) Light-independent reaction enzymes
(b) Light-dependent reaction enzymes
(c) Ribosomes
(d) Chlorophyll

3. Number of thylakoids in a granum is **[AFMC 2008]**
(a) 5-10 (b) 2-100
(c) 100-150 (d) 150-200

4. Consider the following statements with respect to photosynthesis
A. The first carbon dioxide acceptor in C_4 cycle is PGA
B. In C_3 plants, the first stable product of photosynthesis during 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 **[Kerala PMT 2012]**
(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

5. Consider the following statements
(A) The portion of the spectrum between 500nm and 800nm is also referred to as photosynthetically active radiation (PAR)
(B) Magnesium, calcium and chloride ions play prominent roles in the photolysis of water
(C) In cyclic photophosphorylation, oxygen is not released (as there is no photolysis of water) and NADPH is also not produced

Of these statements given above **[Kerala PMT 2008]**
(a) A is true, but B and C are false
(b) A and B are false, but C is true
(c) B is true, but A and C are false
(d) A and B are true, but C is false
(e) A and C are true, but B is false

6. Consider the following statements regarding photosynthesis
(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 phytol tail

Of the above statements **[Kerala PMT 2008]**
(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

7. Which pigment of the plant takes part in light reaction of potosynthesis **[MHCET 2002; Odisha JEE 2009; CPMT 2010]**

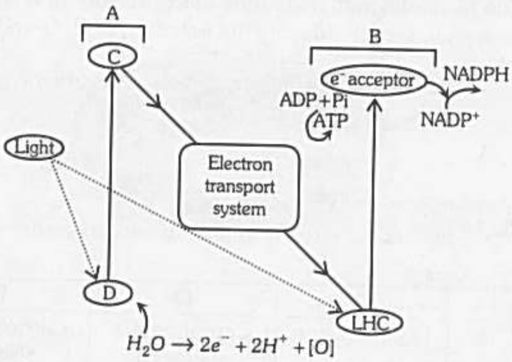
Or

Which pigment is present universally in all green plants **[MP PMT 1999]**
(a) Xanthophyll (b) Chl-a
(c) Carotene (d) Phycoxanthin

8. Photosynthetic pigments in chloroplast are embedded in membrane of **[CBSE PMT 1991]**
(a) Thylakoids (b) Photoglobin
(c) Matrix (d) Envelope of chloroplast

9. The visible portion of light spectrum useful in photosynthesis is referred to as **[MHCET 2015]**
(a) RFLP (b) PAR
(c) VAM (d) VNTR

10. Which of the following pigment is yellow in colour
(a) Chlorophyll '*a*' (b) Chlorophyll '*b*'
(c) Carotene (d) Xanthophyll

11. 

Which of the following is correctly labelled for the given figure **[AIIMS 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 : PS I; B : PS II; C : e^- acceptor; D : LHC
(d) A : e^- acceptor; B : LHC; C : PS II; D : PS I

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

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

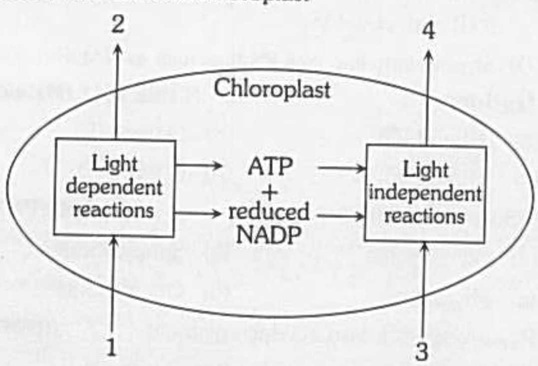
13. Which of the following statement is true with regard to the light reaction of photosynthetic mechanism in plants **[Kerala PMT 2006]**

(a) *Chlorophyll A* occurs with peak absorption at 680 nm in photosystem I and at 700 nm in photosystem II.
(b) Magnesium and sodium ions are associated with photolysis of water molecules.
(c) O_2 is evolved during cyclic photophosphorylation.
(d) Photosystems I and II are both involved in non–cyclic photophosphorylation
(e) Both ATP and $NADPH_2$ are formed during cyclic photophosphorylation

14. Excitation of chlorophyll due to light is a **[BHU 2012]**

(a) Photooxidation reaction (b) Endergonic reaction
(c) Thermochemical reaction (d) Photochemical reaction

15. The given diagram indicates the movement of substances into in and out of a chloroplast



What do labels 1 to 4 represent **[NCERT]**

	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

16. Solarization is **[BHU 2005]**

(a) Formation of chlorophyll
(b) Destruction of chlorophyll
(c) Utilisation of sunlight
(d) Effects of solar light

17. Which statement about photosynthesis is false **[KCET 2009]**

(a) The electron carriers involved in photophosphorylation are located on the thylakoid membranes
(b) Photosynthesis is a redox process in which water is oxidised and carbon dioxide is reduced
(c) The enzymes required for carbon fixation are located only in the grana of chloroplasts
(d) In green plants, both PS-I and PS-II are required for the formation of NADPH + H^+

18. Which one of the following is not true about the light reactions of photosynthesis **[Kerala PMT 2009]**

(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 centres of PS I and PS II respectively
(e) NADPH is not produced in cyclic electron transport in light reactions

19. Which of the following is photophosphorylation **[WB JEE 2008]**

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

20. In chlorophyll structure four pyrrole rings are united with Mg by their atoms of **[AMU (Med.) 2009]**

(a) N (b) C
(c) H (d) O

21. The first acceptor of electrons from an excited chlorophyll molecule of photosystem II is **[CBSE PMT 2007, 08]**

(a) Cytochrome
(b) Iron-sulphur protein
(c) Ferredoxin
(d) Quinone

22. DCMU **[MP PMT 2007]**

(a) Inhibits PS-I
(b) Inhibits PS-II
(c) Destroy chloroplast
(d) Inhibits oxidative phosphorylation

23. $NADPH_2$ is generated through [CBSE PMT 1997]

Or

Ferredoxin is a component of [CBSE PMT 1991]
(a) Glycolysis (b) Photosystem-I
(c) Photosystem-II (d) Anaerobic respiration

24. Photolysis of each water molecule in light reaction will yield [Kerala PMT 2007]
(a) 2 electrons and 4 protons
(b) 4 electrons and 4 protons
(c) 4 electrons and 3 protons
(d) 2 electrons and 2 protons
(e) 1 electron and 2 protons

25. Which of the following statements is true with regard to the light reaction of photosynthesis [Kerala PMT 2011]
(a) In *PS II* the reaction centre chlorophyll *a* has an absorption peak at 700 *nm*, hence is called P 700
(b) In *PS I* the reaction centre chlorophyll *a* has an absorption maxima at 680 *nm* and is called P 680
(c) The splitting of water molecule is associated with *PS I*
(d) Photosystems *I* and *II* are involved in *Z* scheme
(e) Lamellae of the grana have *PS I* and *PS II* and stroma lamellae membranes have *PS II* only

26. Which one of the following statements about the events of noncyclic photophosphorylation is not correct [KCET 2010; J & K CET 2012]
(a) Only one photosystem participates
(b) ATP and NADPH are produced
(c) Photolysis of water takes place
(d) O_2 is released

27. In which stage of photosynthesis, light is directly necessary [CPMT 1996]
(a) For electron exitation
(b) For reduction of CO_2
(c) For regulating photosystem
(d) For cyclic photophosphorylation

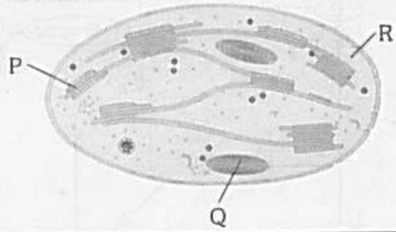
28. The source of O_2 liberated in photosynthesis in green plants is [CPMT 1994, 95; Bihar MDAT 1992; MP PMT 1999, 2002, 10, 12; RPMT 1999]
(a) Photosynthetic enzyme
(b) Carbohydrate present in leaf
(c) Water
(d) Carbon dioxide

29. Photolysis of water takes place in [CPMT 1995]
(a) Calvin cycle (b) Glycolysis
(c) Light phase (d) Dark phase

30. The site of oxygen evolution and photosynthetic phosphorylation in chloroplast are
(a) Matrix (b) Grana stacks
(c) Inner wall of chloroplast (d) Surface of chloroplast

31. The specific function of light energy in the process of photosynthesis is to
(a) Activate chlorophyll (b) Split water
(c) Reduce carbon dioxide (d) Synthesize glucose

32. The given diagram shows the ultra structure of a chloroplast as seen in section. Identify the functions of P, Q and R [NCERT]



	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

33. *NADP* is converted into $NADPH_2$ in
(a) Photosystem–I
(b) Non-cyclic photophosphorylation
(c) Calvin cycle
(d) Photosystem–II

34. The creation of proton gradient across the thylakoid membrane is a result of [AMU (Med.) 2010]
(a) Decrease in proton number in stroma
(b) Accumulation of protons in the lumen
(c) Decrease in the *pH* in the lumen
(d) All of the above

35. 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 into synthesis of ATP and $NADPH_2$
(D) Stroma lamellae lack PS II as well as NADP

Options [CBSE PMT (Mains) 2010]
(a) (B) and (D) (b) (A) and (B)
(c) (B) and (C) (d) (C) and (D)

36. Phtosynthetic unit is [MP PMT 2003]
(a) Glyoxysome (b) Spherosome
(c) Microsome (d) Quantasome

37. P_{700} is a special form of which pigment [RPMT 1997]
(a) Chlorophyll *b* (b) Carotenes
(c) Chlorophyll *a* (d) Phycobilins

38. Water soluble pigments found in plant cell vacuoles are [CPMT 1994; BVP 2000; WB JEE 2011; BHU 2012; NEET (Phase-I) 2016]
(a) Chlorophyll (b) Carotene
(c) Anthocyanin/phycobilin (d) Xanthophyll

39. Where does the primary photochemical reaction occur in chloroplast or Where does the light reactions of photosynthesis take place or Light reaction takes place in **[CPMT 1995, 98; RPMT 1995, 99; MP PMT 1999; Pb. PMT 1999, 2000]**
(a) Stroma
(b) Endoplasmic reticulum
(c) Quantasome or thylakoids (Grana)
(d) Inner membrane of chloroplast

40. The trapping centre of light energy in photosystem–I is **[BHU 2000; BVP 2003]**
Or
Pigment system–I receives radiant energy and releases electron **[MP PMT 1992]**
(a) P–660 (b) P–680
(c) P–700 (d) P–720

41. Blue–green algae shows
(a) Chlorophyll 'a' (b) Chlorophyll 'b'
(c) Both (a) and (b) (d) None of the above

42. Pigment system–I conducts **[Odisha JEE 2011]**
(a) Cyclic photophosphorylation
(b) Non-cyclic photophosphorylation
(c) Both (a) and (b)
(d) None of the above

43. Pigment system–II is concerned with **[MHCET 2000; BHU 2003]**
(a) Photolysis of water (b) Reduction of CO_2
(c) Flowering (d) None of the above

44. The role of chlorophyll in photosynthesis is **[CBSE PMT 2002]**
(a) Absorption of CO_2
(b) Absorption of light
(c) Absorption of light and photochemical decomposition of water
(d) Absorption of water

45. Photophosphorylation is a process in which **[MP PMT 1996]**
(a) Light energy is converted into chemical energy in the form of *ATP*
(b) *NADP* is formed
(c) Chemical energy is used to produce *ATP*
(d) CO_2 is reduced to carbohydrate

46. Which one of the following statements about cytochrome P_{450} is wrong **[CBSE PMT 1998]**
(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

47. Chlorophyll is present
(a) On the surface of chloroplast
(b) In the stroma of chloroplast
(c) In the grana of chloroplast
(d) Dispersed throughout the chloroplast

48. Through which of the following substances the photosystem–I passes an electron to *NADP* during light reactions
(a) Plastocyanin (b) Plastoquinone
(c) Cytochrome (d) Ferredoxin

49. During photochemical reactions of photosynthesis **[NCERT; RPMT 1999; KCET 1994; MDAT 1995]**
(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

50. The core metal of chlorophyll is **[CBSE PMT 1997, 99; AFMC 1999; CPMT 2005]**
Or
Which element is left when chlorophyll is burnt **[CPMT 1993]**
(a) Fe (b) Mg
(c) Ni (d) Cu

51. Hill's reaction takes place in
(a) Dark (b) Light
(c) Dark and light both (d) At any time

52. In photosynthesis light energy is utilized in **[Bihar MDAT 1995; CPMT 1998; MHCET 2003; Odisha JEE 2005]**
(a) Converting *ATP* into ADP
(b) Changing CO_2 into carbohydrate
(c) Converting ADP into *ATP*
(d) All of the above

53. Main pigment involved in transfer of electrons in photosynthesis is **[CPMT 1998]**
(a) Cytochrome (b) Phytochrome
(c) Both (a) and (b) (d) None of these

54. ATP is produced during **[MH CET 2004; MP PMT 2005; CBSE PMT 2009]**
(a) Cyclic photophosphorylation
(b) Non cyclic photophosphorylation
(c) Both
(d) None

55. Splitting of water in photosynthesis is called **[Pb. PMT 2000, 04; MHCET 2001]**
(a) Dark reaction (b) Electron transfer
(c) Photolysis (d) Phototropism

56. Chlorophyll is **[MP PMT 1996; BVP 2002]**
(a) Soluble in organic solvents
(b) Soluble in water
(c) Soluble in both organic solvents and water
(d) None of the above

57. In noncyclic photophosphorylation, the pigment molecule first excited is **[MHCET 2004]**
(a) P_{680} (b) P_{700}
(c) Chlorophyll–b (d) Xanthophyll

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

59. Hill's law in photosynthesis shows **[CPMT 1996]**
(a) Electron exitation (b) Removal of water
(c) Fixation of CO_2 (d) O_2 is obtained from water

60. Chloroplasts absorb light of wavelength **[CPMT 1994]**
(a) $200-300\ m\mu$ (b) $800-1000\ m\mu$
(c) $460-660\ m\mu$ (d) $300-400\ m\mu$

61. The reaction centre for PS-I and PS- II are **[NCERT; MP PMT 2003]**
(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

62. Photo-oxidation of water results in the formation of **[Odisha JEE 2012]**
(a) H^+, O_2 and ATP (b) H^+, O_2, e^- and ATP
(c) H^+, O_2 and e^- (d) None of these

63. Photosystem–I contains **[RPMT 1992]**
(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}

64. Which one of the following elements is required for photosynthetic oxygen evolution **[MP PMT 1998; AMU (Med.) 2012]**
(a) Copper (b) Iron
(c) Manganese (d) Zinc

65. Photolysis of water by isolated chloroplasts was demonstrated by **[AIEEE Pharmacy 2004]**
(a) Robin Hill (b) Van Niel
(c) Liebig (d) Calvin

66. Photosynthetically active radiation (PAR) represents the following range of wavelength **[CBSE PMT 1996, 2005; AIIMS 2007; BHU 2012]**
(a) 340–450 *mm* (b) 400–700 *mm*
(c) 500–600 *mm* (d) 450–950 *mm*

67. Plants adapted to low light intensity have **[CBSE PMT 2004]**
(a) More extended root system
(b) Leaves modified to spines
(c) Larger photosynthetic unit size than the sun plants
(d) Higher rate of CO_2 fixation than the sun plants

68. Hill reaction occurs in **[AIIMS 2003]**
(a) High altitude plants (b) Total darkness
(c) Absence of water (d) Presence of ferredoxin

69. *ATP* formation in photosynthesis is known as **[MP PMT 1993, 2006; CPMT 1998]**
(a) Phosphorylation
(b) Photophosphorylation
(c) Oxidative phosphorylation
(d) None of the above

70. In photosystem-I, the first electron acceptor is **[CBSE PMT 2006]**
(a) Plastocyanin (b) An iron-sulphur protein
(c) Ferredoxin (d) Cytochrome

71. During non-cyclic photophosphorylation in which of the following, $4e^-$ produced through photolysis will enter **[GUJCET 2007]**
(a) $PS-II$ (b) PC
(c) PQ (d) $PS-I$

72. O_2 evolution is directly associated with **[DPMT 2003; BVP 2004]**

Or

Which of the following does not participate when the light reaction synthesizes only *ATP* or performs the cyclic flow of electrons
(a) PS – I (b) PS – II
(c) Phytochrome (d) Phycocyanin

73. H_2 donor during photosynthesis is **[CPMT 2010]**
(a) NADH (b) NADP
(c) ATP (d) NADPH

74. The wavelength of light most absorbed during photosynthesis is **[MP PMT 1998]**
(a) 440 *nm* (b) 550 *nm*
(c) 660 *nm* (d) 700 *nm*

75. The light absorbed by the chlorophyll is at the wave length of **[MP PMT 2002]**
(a) 400 *nm* (b) 500 *nm*
(c) 600 *nm* (d) 660 *nm*

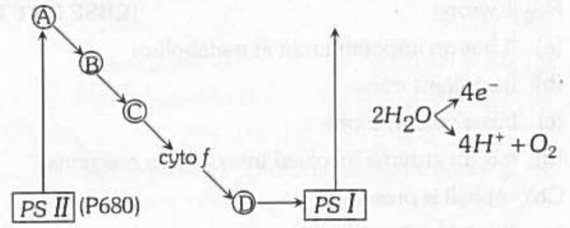
76. Number of chlorophyll arranged per reaction centre in the light harvesting complex are **[Odisha JEE 2005]**
(a) 100 (b) 200
(c) 400 (d) 500

77. Photosystem I and Photosystem II are found in **[CBSE PMT 1992; RPMT 1999; BHU 2001; MP PMT 2001]**
(a) Stroma of chloroplast
(b) Grana of chloroplast
(c) Matrix of mitochondria
(d) Inner membrane of mitochondria

78. Which fractions of the visible spectrum of solar radiations are primarily absorbed by carotenoids of the higher plants **[CBSE PMT 1999]**
(a) Violet and blue (b) Blue and green
(c) Green and red (d) Red and violet

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

80.



In the above schematic diagram, which is plastocyanin **[KCET 2007]**
(a) *C* (b) *D*
(c) *A* (d) *B*

81. How chlorophyll would appear when seen in red light
(a) Red (b) Green
(c) Black (d) Colourless

82. Which one of the following concerns photophosphorylation **[CBSE PMT 1999]**
(a) $AMP + Inorganic\ PO_4 \xrightarrow{\text{Light energy}} ATP$
(b) $ADP + AMP \xrightarrow{\text{Light energy}} ATP$
(c) $ADP + Inorganic\ PO_4 \xrightarrow{\text{Light energy}} ATP$
(d) $ADP + Inorganic\ PO_4 \rightarrow ATP$

83. Who revealed the chemical composition of chlorophyll carotene and xanthophyll
(a) Govindjee (b) Willstatter and Stoll
(c) Park and Biggins (d) Meyers and French

84. Which one is Cu^{++} containing pigment **[CPMT 1999, 2003; MP PMT 2003]**
(a) Ferredoxin (b) Plastocyanin
(c) Plastoquinone (d) Cytochrome

85. The chlorophylls absorb visible light in the region of following wavelengths **[BHU 1994]**
(a) 400 *nm* to 500 *nm* only
(b) 600 *nm* to 800 *nm* only
(c) 400 *nm* to 500 *nm* and 600 *nm* to 700 *nm*
(d) 300 *nm* to 400 *nm* only

Dark reaction

1. Dark reaction of photosynthesis is called
(a) Aphotic action (b) Black action
(c) Blackman's reaction (d) None of the above

2. 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

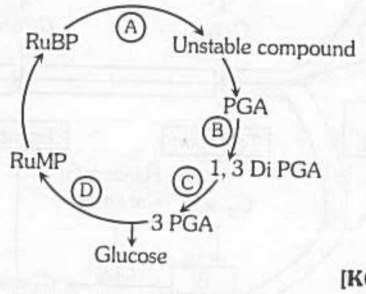
Identify the correct sequence **[Kerala PMT 2006]**
(a) 3 – 1 – 2 (b) 3 – 2
(c) 1 – 2 – 3 (d) 2 – 1– 3
(e) 1 – 3 – 2

3. PGA as the first CO_2 fixation product was discovered in photosynthesis of **[CBSE PMT (Pre.) 2010]**
(a) Alga (b) Bryophyte
(c) Gymnosperm (d) Angiosperm

4. Identify the incorrect statement with respect to Calvin cycle **[KCET 2009]**
(a) The carboxylation of RuBP is catalysed by rubisco
(b) The first stable intermediate compound formed is phosphoglycerate
(c) 18 molecules of ATP are synthesized during carbon fixation
(d) $NADPH + H^+$ produced in light reaction is used to reduce diphosphoglycerate

5. The enzyme responsible for primary carboxylation in C_3 plants is **[Kerala PMT 2009]**
(a) Hexokinase
(b) Succinic dehydrogenase
(c) Pyruvate carboxylase
(d) RuBP carboxylase oxygenase
(e) PEP carboxylase

6. In a condensed schematic representation of dark reaction of photosynthesis given below, steps are indicated by alphabets. Select the option where the alphabets are correctly identified



[KCET 2012]
(a) A = CO_2 fixation, B = Reduction, C = Phosphorylation, D = Regeneration
(b) A = Regeneration, B = CO_2 fixation, C = Reduction, D = Phosphorylation
(c) A = CO_2 fixation, B = Phosphorylation, C = Reduction, D = Regeneration
(d) A = CO_2 fixation, B = Phosphorylation, C = Regeneration, D = Reduction

7. If bundlesheath cells of the C_4 plants are infected by an organism, which utilize CO_2 efficiently then which process will be affected very first **[GUJCET 2014]**
(a) PGAL → RUBP
(b) PGAL + PGA → Glucose
(c) PGA → PGAL
(d) RUBP → PGA

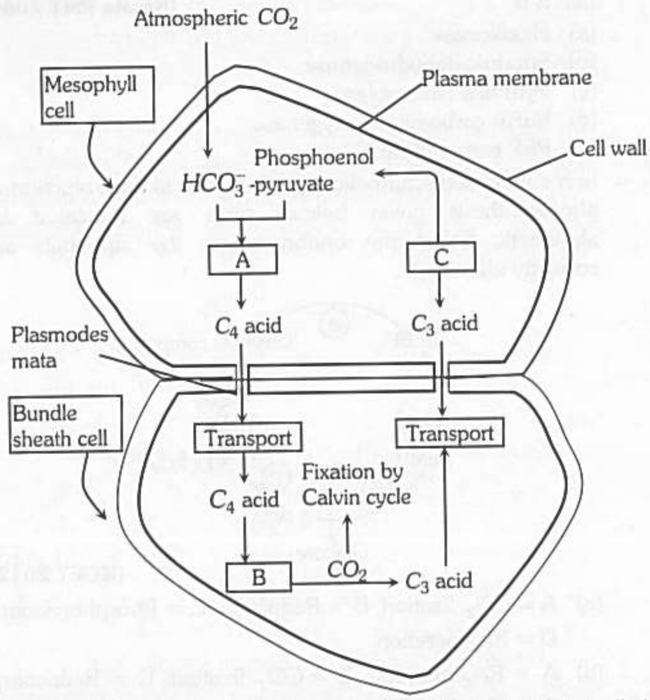
8. For the same amount of CO_2 fixed, a C_4 plant, in comparison with a C_3 plant, loses only **[AMU (Med.) 2009,10]**
(a) Half amount of water (b) Equal amount of water
(c) Double amount of water (d) None of these

9. Which of the following is the main product in the photorespiration of C_3 plants **[CPMT 1999; MP PMT 2010, 12]**
(a) Phosphoglycerate (b) Phosphoglycolate
(c) Glycerate (d) Glycolate

10. During Calvin cycle the total number of CO_2, ATP and NADPH molecules utilized and glucose, ADP and NADP molecules generated is **[AMU (Med.) 2012]**
(a) 31 (b) 36
(c) 61 (d) 67

11. CO_2 joins the photosynthetic pathway during **[MP PMT 1999]**
(a) Light reaction (b) Dark reaction
(c) Photosystem–I (d) Photosystem–II

12. Study the pathway given below



In which of the following options correct words for all the three blanks A, B and C are indicated **[NCERT; CBSE PMT (Mains) 2010]**

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

13. The initial enzyme of Calvin cycle is **[VITEEE 2008]**
(a) Ribulose 1, 5–diphosphate carboxylase
(b) Triose phosphate dehydrogenase
(c) Phosphopentokinase
(d) Cytochrome oxidase

14. During photosynthesis when PGA is changed into phosphoglyceraldehyde, which of the following reaction occur
(a) Oxidation (b) Reduction
(c) Electrolysis (d) Hydrolysis

15. Ribulose diphosphate carboxylase enzyme catalyses the carboxylation reaction between **[MP PMT 2013]**
(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

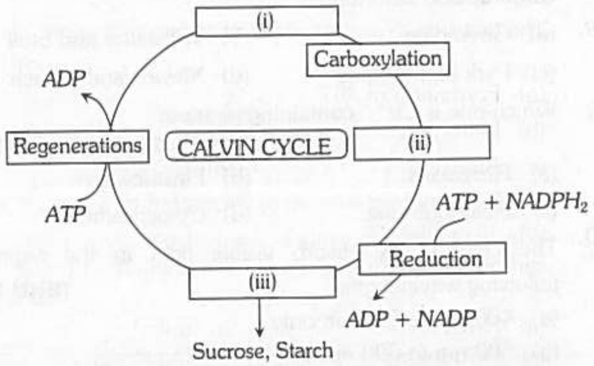
16. Calvin cycle occur in **[MP PMT 1996; BVP 2002]**
(a) Chloroplasts (b) Cytoplasm
(c) Mitochondria (d) Glyoxysomes

17. During dark reaction of photosynthesis
(a) Water split
(b) CO_2 is reduced to organic compounds
(c) Chlorophyll is activated
(d) 6 carbon sugar is broken down into 3 carbon sugar

18. 3-PGA is first stable product in **[DPMT 2007]**
(a) Carbon-reduction cycle (b) OAA
(c) Malic acid (d) PEP

19. In C_3 plants, the first stable product of photosynthesis during dark reaction is **[CPMT 1992, 2009; BHU 1995; RPMT 1995; CBSE PMT 1995; KCET 1998; MP PMT 2000, 06; BVP 2000, 09; DPMT 2006; Kerala PMT 2009]**
(a) 3–phosphoglyceric acid (b) Phosphoglyceraldehyde
(c) Malic acid (d) Oxaloacetic acid

20. Choose the correct combinations of labelling the carbohydrate molecule involved in the Calvin cycle.



[NCERT; Kerala PMT 2007]
(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*

21. One molecule of glucose in Calvin cycle is formed from **[KCET 2006; Odisha JEE 2010]**
(a) $6CO_2 + 12ATP$
(b) $6CO_2 + 30ATP + 12NADPH$
(c) $6CO_2 + 18ATP + 12NADPH$
(d) $6CO_2 + 18ATP + 30NADPH$

22. Calvin cycle is **[CPMT 1995]**
(a) Dependent on light (b) Not dependent on light
(c) Occurs in light (d) None of these

23. How many Calvin cycle form one hexose molecule **[CBSE PMT 1996, 2000]**
(a) 2 (b) 6
(c) 4 (d) 8

24. CO_2 acceptor in C_3 plants is **[CBSE PMT 1995, 96,99; CPMT 1999, 2001; RPMT 2002, 06; J & K CET 2008; WB JEE 2009; AFMC 2010]**
(a) Xylulose–5–phosphate
(b) 3–phosphoglyceric acid
(c) Ribulose 1, 5–diphosphate
(d) Phosphoenol pyruvic acid

25. Which of the following is present in Calvin cycle **[CBSE PMT 1996; AFMC 2008]**
(a) Photophosphorylation
(b) Oxidative carboxylation
(c) Reductive carboxylation
(d) Oxidative phosphorylation

26. In C_3 plants, photosynthesis occur in **[J & K CET 2010]**
(a) Bundles sheath cells (b) Peroxisome
(c) Mesophyll cells (d) Kranz anatomy

27. In which plant Calvin experimented by radioactive isotopy to discover the stable product of C_3 cycle **[Odisha JEE 2005]**
(a) *Chlorella* (b) *Cycas*
(c) Carrot (d) Tobacco

28. Radioactive C^{14} is given to CO_2 and released to atmosphere. This CO_2 is taken by RuBP in a C_3 plant. First radioactive C^{14} is seen in which compound **[Manipal 2005]**
(a) PGAL (b) PEP
(c) RMP (d) PGA

29. The first step in dark reaction of photosynthesis is **[CPMT 2004]**
(a) Formation of ATP
(b) Ionization of water
(c) Attachment of CO_2 to a pentose sugar
(d) Excitement of electron of chlorophyll by a photon of light

30. Which of the following is the first compound that accepts carbon dioxide during dark phase of photosynthesis **[BHU 2004]**
(a) NADP (b) RuBP
(c) Ferridoxin (d) Cytochrome

31. Number of carboxylation occur in Calvin cycle, is **[DPMT 2004]**
(a) 0 (b) 1
(c) 2 (d) 3

32. Reducing power which is transferred from light reaction of photosynthesis to the dark reaction is **[AFMC 2012]**
(a) ATP (b) NADPH
(c) NADH (d) $FADH_2$

C_4/CAM/Photorespiration

1. The family in which many plants are C_4 type
(a) Malvaceae (b) Solanaceae
(c) Crucifereae (d) Gramineae

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 is P_{683} **[Kerala PMT 2008]**
(a) B and C only (b) A only
(c) C only (d) A and B only
(e) A and C only

3. The C_4 plants are photosynthetically more efficient than C_3 plants because
[CBSE PMT 2008; CBSE PMT (Pre.) 2010; AIIMS 2011]
(a) The CO_2 efflux is not prevented
(b) They have more chloroplasts
(c) The CO_2 compensation point is more
(d) CO_2 generated during photorespiration is trapped and recycled through PEP carboxylase

4. In C_4 plants, the bundle sheath cells
[DUMET 2009; NEET (Karnataka) 2013]
(a) Have thin walls of facilitate 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

5. The ratio between 2-carbon and 3-carbon intermediates having $-NH_2$ group formed in photosynthetic oxidation cycle is **[EAMCET 2009]**
(a) 1 : 1 (b) 2 : 1
(c) 3 : 2 (d) 3 : 4

6. The first carbon fixation in C_4 pathway occurs in chloroplasts of **[CBSE PMT 1995; MP PMT 1997; WB JEE 2008]**
(a) Guard cells (b) Mesophyll cells
(c) Bundle sheath cells (d) Epidermal cells

7. An alternate CO_2 fixation mechanism was found some tropical species of grass family by Hatch and Slack, who were from **[AMU (Med.) 2009]**
(a) England (b) USA
(c) Australia (d) New Zealand

8. In a CAM plant the concentration of organic acid **[WB JEE 2009]**
(a) Increases during the day
(b) Decreases or increases during the day
(c) Increases during night
(d) Decreases during any time

9. In photorespiration, what is the role of peroxisome **[GUJCET 2007]**
(a) Help in oxidation of glycolate
(b) Help in oxygenation of glycolate
(c) Help in synthesis of *PGA*
(d) Help in reduction of glyoxylate

10. During photorespiration, the oxygen consuming reaction (s) occur in **[CBSE PMT 2006]**
(a) Grana of chloroplasts and peroxisomes
(b) Stroma of chloroplast
(c) Stroma of chloroplasts and mitochondria
(d) Stroma of chloroplasts and peroxisomes

11. The energy wastage occurs during
(a) Dark respiration (b) Photosynthesis
(c) Glycolysis (d) Photorespiration

12. ....are CAM plant **[Odisha JEE 2005; KCET 2011]**
(a) Maize, papaya (b) Pineapple, agave
(c) Onion, mango (d) Pea, sugarcane

13. Which one is a C_4 plant **[MP PMT 1993, 95; VITEE 2006]**
(a) Sorghum (b) Tribulus
(c) Maize (d) All of these

14. Photorespiration shows formation of **[AIIMS 2012]**
(a) Sugar but not ATP (b) ATP but not sugar
(c) Both ATP and sugar (d) Neither ATP nor sugar

15. In C_4 plants, Calvin cycle occurs in **[CBSE PMT 1994; CPMT 2005]**
(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

16. Photorespiration is characteristic of **[MP PMT 1994; BHU 1995, 2002]**
(a) CAM Plants (b) C_3 Plants
(c) C_4 Plants (d) None of the above

17. C_4 photosynthesis does not occur in **[CPMT 1994; MP PMT 2000]**
(a) *Zea mays*
(b) *Saccharum munja*
(c) *Saccharum officinarum*
(d) *Euphorbia splendens*

18. Which of the following is CO_2 acceptor in C_4 plants **[NCERT; CBSE PMT 1990; CPMT 1994, 98, 2004, 09; BHU 1994, 2000, 01; EAMCET 1995; MP PMT 1996; Odisha PMT 2002; BVP 2002; MHCET 2002; RPMT 2006; Kerala PMT 2007; J & K CET 2010; NEET 2017]**
(a) Phosphoenol pyruvate (PEP)
(b) Ribulose 1, 5–diphosphate (RuDP)
(c) Oxaloacetic acid (OAA)
(d) Phosphoglyceric acid (PGA)

19. Which of the following cycle shows oxaloacetic acid as first stable product **[BHU 2008; J & K CET 2012]**
(a) Calvin cycle (b) Hatch and Slack cycle (C_4)
(c) C_2 cycle (d) None of the above

20. Kranz type of anatomy is found in **[CBSE PMT 1990; RPMT 1995, 97; MH CET 2006; J & K CET 2008; AFMC 2009; CBSE PMT (Mains) 2010; AIIMS 2012; WB JEE 2016]**
(a) C_2 plants (b) C_3 plants
(c) C_4 plants (Sugarcane) (d) CAM plants

21. During photorespiration which compounds are formed having 2C and 3C respectively in Peroxisome **[GUJCET 2015]**
(a) Glycolate, Glycine
(b) Glycine, Glycerate
(c) Serine, Glycine
(d) Phosphoglycerate, Glycolate

22. C_4 plants are adapted to **[NCERT; BHU 2002]**
(a) Hot and dry climate (b) Temperate climate
(c) Cold and dry climate (d) Hot and humid climate

23. Which one of the following is wrong in relation to photorespiration **[CBSE PMT 2003]**
(a) It is a characteristic of C_3 plants
(b) It occurs in chloroplasts
(c) It occurs in day time only
(d) It is a characteristic of C_4 plants

24. 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 (Phase-I) 2016]**
(a) C_3 (b) C_4
(c) CAM (d) Nitrogen fixer

25. Which one of the following is a CAM plant **[MHCET 2015]**
(a) Maize (b) *Kalanchoe*
(c) Sugarcane (d) Jowar

26. Select the incorrect matched pair with regard to C_4 cycle **[Kerala PMT 2011]**

(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

27. CAM helps the plants in **[CBSE PMT (Pre.) 2011]**
(a) Reproduction (b) Conserving water
(c) Secondary growth (d) Disease resistance

28. Agranal chloroplasts occur in certain **[MP PMT 1995, 98]**

Or

Atriplex spongiosa is a
(a) Succulents (b) C_4 plants
(c) Hydrophytes (d) C_3 plants

29. In the leaves of C_4 plants, malic acid formation during CO_2 fixation occurs in the cells of **[CBSE PMT 2007, 08]**
(a) Mesophyll (b) Bundle Sheath
(c) Phloem (d) Epidermis

30. Which of the following plants stand intermediate between C_3 and C_4 plants
(a) *Triticum aestivum* (b) *Zea mays*
(c) *Panicum milioides* (d) All the above

31. Chloroplasts without grana are known to occur in **[KCET 2006]**
(a) Bundle sheath cells of C_3 plants
(b) Mesophyll cells of C_4 plants
(c) Bundle sheath cells of C_4 plants
(d) Mesophyll cells of all plants.

32. Which crop utilises solar energy most efficiently **[BHU 2006]**
(a) Potato (b) Sugarcane
(c) Wheat (d) Rice

33. In maximum plants stomata open during day and closed in night. Its exception is **[Pb. PMT 2004; AMU (Med.) 2005]**
(a) Crassulacean acid metabolism plants
(b) C_3 plants
(c) C_4 plants
(d) None of these

34. Correlation between 'Kranz' anatomy and C_4 path of CO_2 assimilation was first established by
(a) Hill and Bendall (b) Calvin
(c) Dowton and Treguna (d) Arnold

35. The glycolate metabolism occur in **[MP PMT 1995, 2000, 01; RPMT 1999; BHU 2001; AIIMS 2001; BVP 2003; WB JEE 2010]**
(a) Lysosomes (b) Ribosomes
(c) Glyoxysomes (d) Peroxisomes

36. Members of family Crassulaceae perform **[MHCET 2004]**
(a) C_3 photosynthesis (b) CAM photosynthesis
(c) C_4 photosynthesis (d) All of the above

37. In Kranz anatomy, the bundle sheath cells have **[CBSE PMT (Mains) 2011]**
(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 large number of chloroplasts

38. Source of CO_2 for photosynthesis during day in CAM plant is **[CPMT 2005]**
(a) 3-PGA (b) Malic acid
(c) Oxalo-acetic acid (d) Pyruvate

39. Which of the following is a 4-carbon compound **[Kerala PMT 2010]**
(a) Oxaloacetic acid (b) Phosphoglyceric acid
(c) Ribulose bis phosphate (d) Phosphoenol pyruvate
(e) Citric acid

40. Sugarcane show high efficiency of CO_2 fixation because of **[CPMT 2004]**
(a) Calvin cycle (b) Hatch and Slack cycle
(c) TCA cycle (d) Greater sunlight

41. In C_4-plants, the carbon dioxide fixation occurs in **[BHU 2004]**
(a) Guard cells (b) Spongy cells
(c) Palisade cells (d) Bundle sheath cells

42. Photorespiration is favoured by **[CBSE PMT 1991; BHU 2002; BVP 2003]**
(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

43. Photosynthesis in C_4 plants is relatively less limited by atmospheric CO_2 levels because **[CBSE PMT 2005]**
(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 bundlesheath cells
(d) Rubisco in C_4 plants has higher affinity for CO_2

44. Which of the following statements regarding C_4 pathway is false **[Kerala PMT 2010, 12]**
(a) The primary CO_2 acceptor is 5 carbon molecule
(b) The enzyme responsible for CO_2 fixation is PEP case
(c) The mesophyll cell lack RuBisCO enzyme
(d) The C_4 acid OAA is formed in the mesophyll cells
(e) The bundle sheath cells contain the enzyme PEP case

45. CAM photosynthesis occurs in plants with **[MP PMT 1993]**
(a) Thin green leaves with reticulate venation
(b) Thin green leaves with parallel venation
(c) Fleshy green leaves
(d) Thin coloured leaves

46. C_4 plant shows efficiency even in **[HPMT 2005]**
(a) Low CO_2 concentration (b) Low temperature
(c) High O_2 concentration (d) At low water

47. In sugarcane plant $^{14}CO_2$ is fixed in malic acid, in which the enzyme that fixes CO_2 is **[CBSE PMT 1999]**
(a) Fructose phosphatase
(b) Ribulose biphosphate carboxylase
(c) Phosphoenol pyruvic acid carboxylase
(d) Ribulose phosphate kinase

48. A process that makes important difference between C_3 and C_4 plants is **[CBSE PMT (Pre.) 2012; NEET (Phase-II) 2016]**
(a) Transpiration (b) Glycolysis
(c) Photosynthesis (d) Photorespiration

49. Which of the statements is not true of the C_4 pathway **[AIEEE Pharmacy 2004]**
(a) It requires more energy than the C_3 pathway for 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 high CO_2 concentration

50. Photorespiration is called **[MHCET 2000; VITEEE 2006; J & K CET 2010]**
(a) C_2 cycle (b) C_3 cycle
(c) C_4 cycle (d) None of these

51. The first reaction in photorespiraton is **[RPMT 1999; CBSE PMT 2000; CPMT 2001]**
(a) Carboxylation
(b) Decarboxylation
(c) Oxygenation
(d) Phosphorylation

52. In photorespiration glycolate is converted to CO_2 and serine in **[AIEEE Pharmacy 2003]**
(a) Chloroplasts (b) Peroxisomes
(c) Vacuoles (d) Mitochondria

53. No. of carboxylation in C_4 cycle is/are **[DPMT 2003]**
(a) 1 (b) 2
(c) 5 (d) 3

54. In Hatch and Slack pathway [BHU 2003]
(a) Chloroplast are of 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

55. The enzyme which catalyzes the photosynthetic C_4 cycle is
Or
In C_4 plants, CO_2 combine with PEP in presence of
(a) RuDP carboxylase (b) PEP carboxylase
(c) Carbonic anhydrase (d) None of these

56. Peroxysomes are found in [Odisha JEE 2005]
(a) Bundle sheath (b) Endosperm
(c) Mesophyll cells (d) Vascular bundle

57. Peroxysome are related with [PUNE CET 1998; MP PMT 1998, 04, 05; AMU (Med.) 2005]
(a) Photosynthesis (b) Photorespiration
(c) Respiration (d) None

58. Photorespiration takes place is [BHU 1994, 2000, 01; MP PMT 2000, 01, 09; AIIMS 2001, 02; Kerala PMT 2002, 08; CPMT 2005; Odisha JEE 2011; CBSE PMT (Pre.) 2012]
Or
Photorespiratory reactions are operated in
(a) Chloroplast, mitochondria
(b) Mitochondria, peroxysome
(c) Chloroplasts, peroxysome, mitochondria
(d) Chloroplasts, cytoplasm, mitochondria

59. Which one is false about kranz anatomy [CPMT 2005]
(a) Bundle sheath have large chloroplast and less developed grana
(b) Mesophyll cells have large chloroplast and more
(c) It is found in *Atriplex*, sugarcane, maize
(d) Plant having it have better photosynthesizing power than C_3 plants

60. The entire reactions of C_4 pathway takes place in [WB JEE 2016]
(a) Mesophyll and bundle sheath
(b) Vascular bundle and palisade tissue
(c) Mitochondria and peroxisome
(d) Bundle sheath and endoplasmic reticulum

Bacterial photosynthesis

1. Bacteria that uses chemical energy to fix CO_2 are known as [Odisha JEE 2010]
(a) Chemoautotroph (b) Photoautotroph
(c) Heterotroph (d) None of these

2. All life on earth derive its energy directly or indirectly from sun except [CBSE PMT 1994]
(a) Mushroom and mould (b) Chemosynthetic bacteria
(c) Symbiotic bacteria (d) Pathogenic bacteria

3. Which one of the following categories of organisms do not evolve oxygen during photosynthesis [CPMT 1999, 2003; JIPMER 1999; AIIMS 2004; RPMT 2006]
(a) Red algae
(b) Photosynthetic bacteria
(c) C_4 plants with Kranz anatomy
(d) Blue green algae

4. The site of photosynthesis in blue green algae is [MP PMT 2009]
Or
Photosynthetic bacteria have pigments in [CBSE PMT 1999; RPMT 1999; Bihar CECE 2006]
(a) Chromatophores (b) Mitochondria
(c) Chloroplast (d) Root hair

5. In the bacterial photosynthesis, hydrogen donor is
(a) H_2S (b) NH_2
(c) H_2O (d) H_2SO_4

6. Which wavelength of light carry out photosynthesis in bacteria
(a) Ultraviolet light (b) Blue
(c) Red (d) Far red

7. *Leptothrix* is a
(a) Nitrifying bacteria (b) Sulphur bacteria
(c) Iron bacteria (d) Hydrogen bacteria

8. Green bacteria contains
(a) Chlorobium chlorophyll–660
(b) Chlorobium chlorophyll–650
(c) Both (a) and (b)
(d) Chlorobium chlorophyll–700

9. Bacterial photosynthesis takes place in [RPMT 1995]
(a) Cytoplasm (b) Chromoplast
(c) Chloroplast (d) Oxysome

10. Chlorophyll *a* is absent in which of the following photosynthetic organism [BVP 2004]
(a) Cyanobacteria (b) Red algae
(c) Brown algae (d) Bacteria

11. Which of the following bacteria grow on isopropyl alcohol and convert it into acetone
(a) Fermentative bacteria
(b) Chemosynthetic bacteria
(c) Photosynthetic purple non-sulphur bacteria
(d) Nitrifying bacteria

12. Bacterial photosynthesis involves …….. [KCET 2004]
(a) Both PS–I and PS–II (b) Either PS–I or PS–II
(c) PS–I only (d) PS–II only

13. Which of the following photosynthetic bacteria have both PS–I and PS–II

Or

Which was first photosynthetic organism **[BVP 2004]**

(a) Green sulphur bacteria (b) Purple sulphur bacteria
(c) Cyanobacteria (d) Purple non-sulphur bacteria

Factors affecting photosynthesis

1. Which of the following inhibits O_2 release in light phase **[DPMT 2004]**
(a) PMA (b) Zeatin
(c) DCMU (d) None of these

2. Which factor is not limiting in normal conditions for photosynthesis **[MHCET 2003]**
(a) Air (b) CO_2
(c) Water (d) Chlorophyll

3. Blackman's law of limiting factor is applied to **[NCERT; RPMT 1999; AIIMS 2001]**
(a) Growth (b) Respiration
(c) Transpiration (d) Photosynthesis

4. The algae found in high temperature ponds are capable of doing photosynthesis upto
(a) 30° *C* (b) 75° *C*
(c) 90° *C* (d) 100° *C*

5. What is called Warburg's effect on photosynthesis **[MP PMT 2003]**
(a) Low rate of the process due to O_2 supply
(b) Low rate of the process due to CO_2 supply
(c) Both (a) and (b)
(d) None of the above

6. When $NaHCO_3$ is added in small quantity in an experiment showing photosynthesis, what will be the effect on it
(a) Rate will be lowered (b) Rate will be increased
(c) Rate will be normal (d) Process will stop

7. The most effective wavelength of visible light in photosynthesis is in the region of **[CBSE PMT 1999; RPMT 1999; CPMT 2000, 10; MP PMT 2000, 10,11; Kerala CET 2003; AFMC 2003; DPMT 2004]**
(a) Violet (b) Green
(c) Yellow (d) Red

8. Compensation point is **[CPMT 1998, 99; AFMC 2002]**
(a) Where there is neither photosynthesis nor respiration
(b) When 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 plant

9. Which one of the following is not a limiting factor for photosynthesis **[KCET 1999]**
(a) Oxygen (b) Carbon dioxide
(c) Chlorophyll (d) Light

10. If the rate of translocation of food is slow, what will be the effect on photosynthesis
(a) It will increase (b) It will remain same
(c) Becomes double (d) It will decrease

11. Which of the following wavelength of light is absorbed maximum for photosynthesis

Or

Chl. a absorb's max of **[MP PMT 2005]**
(a) Red light (b) Blue light
(c) Green light (d) Yellow light

12. In which of the following the rate of photosynthesis is decreased and is known as red drop **[MP PMT 1992]**
(a) Blue light
(b) Green light
(c) Red light more than 680 *nm*
(d) Red light less than 680 *nm*

13. Q_{10} refers to **[RPMT 1997]**
(a) Quality quotient (b) Temperature quotient
(c) Respiratory quotient (d) Quantum constant

14. A plant is kept in 300*ppm* CO_2 concentration, what will happen to it
(a) Plant will die soon
(b) Plant will grow but will not die
(c) Plant will show normal photosynthesis
(d) Respiration will be greatly decreased

15. What will be the effect of intermittent light on photosynthesis
(a) It will increase (b) It will decrease
(c) Will not be effected (d) Process will stop

16. What will be the effect when very high intensity of light is supplied to a photosynthesis system
(a) Process will increase
(b) Process will decrease
(c) Process will stop due to solarization
(d) None of the above

17. Which of the following conditions are favourable for cyclic photophosphorylation **[CPMT 1999]**
(a) Anaerobic condition
(b) Aerobic and optimum light
(c) Aerobic and low light intensity
(d) Anaerobic and low light intensity

18. Plants which can photosynthesize at as low temperature (upto –35° *C*) are
(a) Conifers (b) Blue–green algae
(c) Xerophytes (d) Tropical plants

19. When a photosynthetic plant is transferred to an atmosphere of enriched O_2, its rate of
(a) Photosynthesis would increase
(b) Photosynthesis would decrease
(c) Respiration would decrease
(d) Osmosis would increase

20. Under conditions of constant illumination, the compensation period for a whole aquarium would be of infinite length when
(a) The biomass of animals equals the biomass of plants
(b) The respiratory exchanges of the animals are equal to the photosynthetic exchanges of the plants
(c) The oxygen intake of the animals equals of oxygen output of photosynthesis
(d) The carbon dioxide output of the animals and plants equals to the photosynthetic intake of the plants

21. In nature the photosynthesis should proceed upto the limit of
(a) Light (b) Temperature
(c) CO_2 (d) Moisture and wind

22. Which of the following would happen if the supply of O_2 is decreased to an illuminated wheat plant
(a) Its photosynthesis would decrease
(b) Its respiration would increase
(c) Its photosynthesis would increase
(d) All the physiological process would stop

23. 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 up to 0.05% can enhance CO_2 fixation rate
(c) C_3 plants respond 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

NQ NCERT Exemplar Questions

1. Which metal ion is a constituent of chlorophyll **[NCERT]**
(a) Iron (b) Copper
(c) Magnesium (d) Zinc

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

3. Chemosynthetic bacteria obtain energy from **[NCERT]**
(a) Sun (b) Infra red rays
(c) Organic substance (d) Inorganic chemicals

4. Energy required for ATP synthesis in PSII comes from **[NCERT]**
(a) Proton gradient (b) Electron gradient
(c) Reduction of glucose (d) Oxidation of glucose

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

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

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

8. Splitting of water is associated with **[NCERT]**
(a) Photosystem I
(b) Lumen of thylakoid
(c) Both Photosystem I and II
(d) Inner surface of thylakoid membrane

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

10. The enzyme that is not found in a C_3 plant is **[NCERT]**
(a) RuBP Carboxylase (b) PEP Carboxylase
(c) NADP reductase (d) ATP synthase

11. The reaction that is responsible for the primary fixation of CO_2 is catalysed by **[NCERT]**
(a) RuBP carboxylase
(b) PEP carboxylase
(c) RuBP carboxylase and PEP carboxylase
(d) PGA synthase

CT Critical Thinking Objective Questions

1. Which is the evidence to show that O_2 is released in 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

2. What effect would occur on photosynthesis, if the amount of oxygen in the atmosphere decreases **[RPMT 1997]**
   (a) Increase in C_3 cycle and decrease in C_4 cycle
   (b) Increase in C_4 cycle and decrease in C_3 cycle
   (c) Increase in C_3 cycle and no change in C_4 cycle
   (d) Increase in C_4 cycle and no change in C_3 cycle

3. Read the following four statements (A-D)
   (A) Both, photophosphorylation and oxidative phoshorylation 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 free-living state also in soil

   How many of the above statements are right **[CBSE PMT (Mains) 2012]**
   (a) Two (b) Three
   (c) Four (d) One

4. Which of the following may show photosynthesis in moonlight
   (a) Some thermal algae (b) Some marine algae
   (c) Some fresh water algae (d) None of the above

5. $$4H_2O \rightarrow 4H^+ + 4OH^-$$

   In this process which of the following play important role **[GUJCET 2015; MHCET 2015]**
   (a) Chlorophyll (b) Light energy
   (c) Ca^{++}, Mn^{++}, Cl^- (d) All of the above

6. Chloroplast contains maximum quantity of **[BCECE 2005, 06]**
   (a) Pyruvic carboxylase (b) Hexokinase
   (c) RuBP carboxylase (d) None of the above

7. What is common between photosynthesis and respiration **[MP PMT 1993, 96, 2003, 06; BHU 1995; AFMC 1995; Haryana PMT 2005; MH CET 2005; DPMT 2006; KCET 2006]**
   (a) Cytochrome (b) Light
   (c) H_2O (d) Temperature

8. Photosynthesis is **[NCERT; MH CET 2002; Odisha JEE 2012; MP PMT 2013]**
   (a) Oxidative, exergonic, catabolic
   (b) Reductive, endergonic, anabolic
   (c) Reductive, exergonic, anabolic
   (d) Reductive, endergonic, catabolic

9. Which of the following can photosynthesize at low temperature ($-20^\circ C$) **[BVP 2000]**
   (a) Bacteria (b) Lichen
   (c) Yeast (d) *Batrachospermum*

10. The electron transport chain of photosynthetic process is **[JIPMER 2002]**
    (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

11. What percentage of usable radiant energy entering a reaction site of photosynthesis is converted to potential energy **[BHU 2002]**
    (a) 10% (b) 20%
    (c) 35% (d) 42%

12. Chlorophyll 'a' is found in **[CBSE PMT 1992]**
    (a) All oxygen releasing photosynthetic forms
    (b) All plants except fungi
    (c) All higher plants that photosynthesize
    (d) All photosynthetic prokaryotes and eukaryotes

13. The empirical formula for chlorophyll 'a' is **[KCET 1994, 2000; AFMC 1994; Wardha 2005; J & K CET 2008; WB JEE 2016]**
    (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) $C_{54}H_{70}O_6N_4Mg$

14. Which of the following is wrongly matched **[Kerala PMT 2010]**
    (a) Sorghum - Kranz Anatomy
    (b) PEP carboxylase - Mesophyll cells
    (c) Blackman - Law of limiting factors
    (d) Photorespiration - C_3 plants
    (e) PS II - P700

15. Chlorophyll 'a' molecule at its carbon atom 3 of the pyrrole ring II has one of the following **[CBSE PMT 1996, 97]**
    (a) Aldehyde group (b) Methyl group
    (c) Carboxylic group (d) Magnesium

16. Bacteriochlorophyll differs from chlorophyll 'a' in having
    (a) One pyrrol ring with one hydrogen
    (b) One pyrrol ring with two hydrogen
    (c) One pyrrol ring with three hydrogen
    (d) One pyrrol ring with four hydrogen

17. In photosynthesis, photolysis of water is used in **[CPMT 1998]**
    (a) Reduction of *NADP* (b) Oxidation of *NADP*
    (c) Oxidation of *FAD* (d) None of these

18. C_4 plants are found among

(a) Gramineae only (b) Monocots only

(c) Dicots only (d) Monocots as well as dicots

19. Energy transfer in photosynthesis occurs as **[BHU 2003]**

(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*

20. Photosynthesis consists of essentially two biological reaction systems, one followed by the other, the second of these systems does which of the following

(a) Fixes CO_2

(b) Traps light energy

(c) Synthesizes starch

(d) Works only in the presence of light

21. During dark reaction for fixation of carbon, the three carbon atoms of each molecule of 3-phosphoglyceric acid (PGA) are derived from **[BHU 1994]**

(a) *RuBP* only (b) CO_2 only

(c) $RuBP + CO_2$ (d) $RuBP + CO_2 + PEP$

22. Calvin's cycle is found in **[RPMT 1997]**

(a) Only C_3 plants (b) Only photophillous plants

(c) All C_4 plants (d) All photosynthetic plants

23. The first intermediate formed during photosynthesis is **[CPMT 2000]**

(a) Fructose 1, 6-diphosphate

(b) Ribulose 1, 5-biphosphate

(c) Xylulose-5-phosphate

(d) Phosphoglyceraldehyde

24. First transitory chemical formed by reaction between CO_2 and *RuBP* is **[J & K CET 2002]**

(a) PGAL/GAP

(b) 2–Carboxy, 3- keto, 1-5–biphospho ribotol

(c) PGA

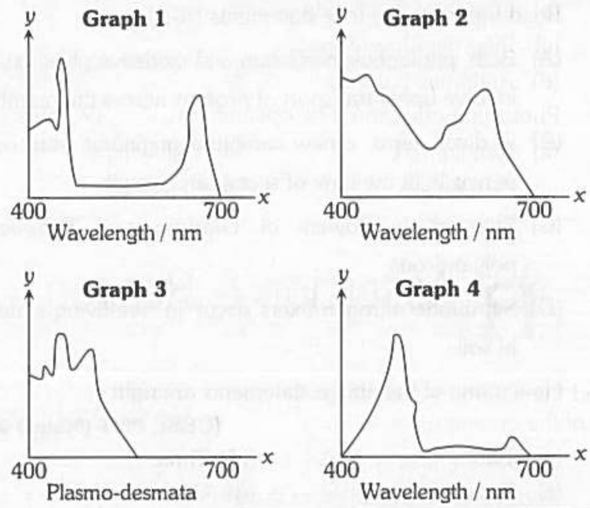
(d) Dihydroxy acetone phosphate

25. As compared to a C_3 plant, how many additional molecules of ATP are needed for net production of one molecule hexose sugar by C_4 plants **[CBSE PMT 2005]**

(a) Two (b) Six

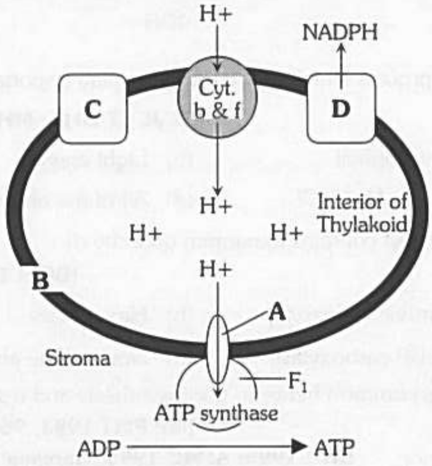
(c) Zero (d) Twelve

26. 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.
All the x axis show wavelength. Three of the y axis show light absorption. One y axis shows the rate of photosynthesis **[NCERT]**



	Chlorophyll a	Absorption Chlorophyll b	Spectra Carotenoids	Action spectrum
(a)	3	2	4	1
(b)	2	4	3	1
(c)	2	1	3	4
(d)	1	4	3	2

27. Observe the pathway of ATP synthesis through chemiosmosis given below



Select the right answer in which correct words for all the four blanks A, B, C and D are indicated **[NCERT]**

(a) A - F_0, B - Thylakoid membrane, C - Photosystem (II), D - Photosystem (I)

(b) A - F_1, B - Thylakoid membrane, C - Photosystem (II), D Photosystem (I)

(c) A - F_0, B - Thylakoid membrane, C - Photosystem (I), D - Photosystem (II)

(d) A - F_1, B - Thylakoid membrane, C - Photosystem (I), D - Photosystem (II)

28. Chromatophores take part in [AIPMT 2015]
(a) Growth (b) Movement
(c) Respiration (d) Photosynthesis

29. In a chloroplast the highest number of protons are found in [NEET (Phase-I) 2016]
(a) Stroma
(b) Lumen of thylakoids
(c) Inter membrane space
(d) Antennae complex

30. Photosynthesis cannot be operated in [WB JEE 2016]
(a) Red light (b) Yellow light
(c) Green light (d) Blue light

AR 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 : C_4 pathway of CO_2 fixation is found in some tropical plants.
Reason : In this pathway CO_2 is fixed by 3C compound. [AIIMS 1998]

2. 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 $NADPH_2$ [AIIMS 2002]

3. Assertion : Rhoeo leaves contain anthocyanin pigments in epidermal cells.
Reason : Anthocyanins are accessory photosynthetic pigments. [AIIMS 2003]

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

5. Assertion : The concentration of O_2 in the atmosphere is inhibitory to photosynthesis.
Reason : Oxygen inhibitory effect is due to Warburg effect.

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

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 : Plants utilizing first *RuBP* in CO_2 fixations are called C_3 plants.
Reason : Plants utilizing first PEP in CO_2 fixations are called C_4 plants.

9. 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. [AIIMS 2004, 07]

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

11. Assertion : Cyclic photophosphorylation synthesizes ATP.
Reason : ATP synthesize in cyclic photophosphorylation is not associated with NADPH formation.

12. Assertion : Oxidative phosphorylation requires oxygen.
Reason : Oxidative photophosphorylation occurs in mitochondria.

13. 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.

14. 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.

15. Assertion : One molecule of CO_2 is fixed to give 686 *kcal* in photosynthesis.
Reason : To form a hexose, six molecules of CO_2 are fixed.

16. Assertion : In the formation of one glucose, 686,000 calories energy are produced.
Reason : The energy is provided by a total of 12 NADPH and 18 ATP.

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

18. Assertion : Plants utilize 5-10% of the absorbed water in photosynthesis.
Reason : Reduced leaf hydration decrease the photosynthesis.

Answers

History of photosynthesis

1	a	2	b	3	c	4	a	5	a
6	b	7	d	8	d	9	d	10	b
11	d	12	c	13	a	14	c	15	a
16	b								

Experiments

1	b	2	d	3	a	4	a	5	d
6	b	7	b	8	d	9	b	10	a
11	a	12	b	13	c				

Photosynthetic apparatus

1	a	2	b	3	d	4	b	5	b
6	e	7	b	8	a	9	b	10	d
11	c	12	d	13	b	14	e	15	c
16	d	17	b	18	d	19	b	20	b
21	c	22	b	23	d	24	d	25	a
26	a	27	a	28	a	29	a	30	b
31	d	32	b	33	d	34	c	35	b
36	b	37	d						

Light reaction/Pigments

1	c	2	a	3	b	4	c	5	b
6	a	7	b	8	a	9	b	10	d
11	a	12	c	13	d	14	a	15	b
16	b	17	c	18	d	19	b	20	a
21	d	22	b	23	b	24	d	25	d
26	a	27	a	28	c	29	c	30	b
31	a	32	b	33	b	34	d	35	a
36	d	37	c	38	c	39	c	40	c
41	a	42	a	43	a	44	c	45	a
46	c	47	c	48	d	49	c	50	b
51	b	52	c	53	a	54	c	55	c
56	a	57	a	58	a	59	d	60	c
61	a	62	c	63	c	64	c	65	a
66	b	67	d	68	d	69	b	70	b
71	a	72	b	73	d	74	a	75	d
76	b	77	b	78	a	79	c	80	b
81	c	82	c	83	b	84	b	85	c

Dark reaction

1	c	2	a	3	a	4	c	5	d
6	c	7	d	8	b	9	d	10	d
11	b	12	c	13	a	14	b	15	b
16	a	17	b	18	a	19	a	20	d
21	c	22	b	23	b	24	c	25	c
26	c	27	a	28	d	29	c	30	b
31	b	32	b						

C_4/CAM/Photorespiration

1	d	2	d	3	b	4	d	5	b
6	b	7	c	8	c	9	a	10	d
11	d	12	b	13	d	14	d	15	a
16	b	17	d	18	a	19	b	20	c
21	b	22	a	23	d	24	b	25	b
26	a	27	b	28	b	29	a	30	c
31	c	32	b	33	a	34	c	35	d
36	b	37	d	38	b	39	a	40	b
41	d	42	d	43	b	44	a, e	45	c
46	a	47	c	48	d	49	c	50	a
51	c	52	d	53	b	54	b	55	b
56	c	57	b	58	c	59	b	60	a

Bacterial photosynthesis

1	a	2	b	3	b	4	a	5	a
6	d	7	c	8	c	9	a	10	d
11	c	12	c	13	c				

Factors affecting photosynthesis

1	c	2	d	3	d	4	b	5	a
6	b	7	d	8	b	9	a	10	d
11	b	12	c	13	b	14	c	15	a
16	c	17	d	18	a	19	b	20	d
21	b	22	c	23	c				

NCERT Exemplar Questions

1	c	2	a	3	d	4	a	5	c
6	a	7	d	8	d	9	a	10	b
11	c								

Critical Thinking Questions

1	d	2	c	3	a	4	b	5	d
6	c	7	a	8	b	9	b	10	b
11	c	12	a	13	c	14	e	15	b
16	b	17	a	18	d	19	c	20	a
21	c	22	d	23	d	24	b	25	d
26	d	27	a	28	d	29	b	30	c

Assertion and Reason

1	b	2	b	3	c	4	b	5	a
6	a	7	c	8	b	9	b	10	d
11	b	12	b	13	c	14	e	15	e
16	a	17	e	18	e				

Answers and Solutions

History of photosynthesis

1. (a) Blackman propounded the law of limiting factors. He also proposed the occurrence of a dark phase in photosynthesis.

3. (c) The discovery of Emerson effect. One group of pigments absorbs light of both shorter and longer wavelengths (more than 680*nm*) and another group of pigment absorbs light of only shorter wavelengths (less than 680*nm*). These two groups of pigments are known as pigment systems or photosystems.

4. (a) Malvin Calvin (1954) traced the pathway of carbon in photosynthesis and gave the C_3 cycle, (now known after him as calvin cycle). He was awarded Nobel prize for this work in 1960.

5. (a) Malvin calvin and his coworkers in 1954 by using the methods of radio active tracer technique, chromatography and Autoradiography.

6. (b) Arnon etal. (1954) first of all demonstrated that isolated chloroplasts can produce ATP from ADP+ip and they called this ATP production as photophosphorylation.

7. (d) Pelletier and Caventou (1818) discovered chlorophyll. It could be separated from leaf by boiling in alcohol.

8. (d) Robert Mayer (1845) proposed that light has radiant energy and this radiant energy is converted into chemical energy by plants, which serves to maintain life of the plants and also animals.

9. (d) Thylakoids (Menke, 1961) or baggy trousers are structural elements of chloroplast.

10. (b) According to Jan Ingen-Housz (1779), both green parts and sunlight are required for air purification and plant nourishment.

11. (d) Bousingault (1860) reported that amount of O_2 evolved in photosynthesis is equal to amount of CO_2 absorbed and both these processes occur simultaneously as soon as light is given.

12. (c) Helmont concluded that "all food of the plant is derived from rain water and not from soil and all parts of the plant develop from water".

14. (c) Hatch and Slack (1965) discovered the C_4 pathway for CO_2 fixation in certain tropical grasses.

15. (a) In 1930 C.B. Van Niel proved that, sulphur bacteria use H_2S (in place of water) and CO_2 to synthesize carbohydrates as follows :

$$6CO_2 + 12H_2S \longrightarrow C_6H_{12}O_6 + 6H_2O + 12S$$

This led Van Niel to the pastulation that in green plants, water (H_2O) is utilized in place of H_2S and O_2 is evolved in place of sulphur (S). He indicated that water is electron donar in photosynthesis.

$$6CO_2 + 12H_2O \longrightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$$

Experiments

2. (d) Both blue and red wavelength are affective because the amount of oxygen released was found to be maximum in blue and red absorption bands of the chlorophyll.

3. (a) During photosynthesis O_2 evolved by the hydrolysis of water. If H_2O^{18} is used in 'A' plant then it become true that O^{18} type oxygen evolved from 'A' plant during photosynthesis.

4. (a) C^{14} isotope used for knowing carbon path and O^{18} used for verified that source of O_2 in photosynthesis is H_2O, not CO_2.

6. (b) Ruben and Kamen used C^{14} radioactive isotopes in *chlorella* for knowing path of carbon in photosynthesis.

9. (b) Calvin traced the path in photosynthesis associated with dark reaction. Radioactive isotope of carbon (C^{14}) is used, it is observed that ($C^{14}O_2$) reduction of CO_2 is definitely in dark reaction.

10. (a) Calvin used isotopes C^{14} in *chlorella* for knowing carbon path in photosynthesis. Chlorella is a unicellular alga is using by Ruben Kamen and warburg. Because algae carry out 90% of photosynthesis.

11. (a) Photolysis occur in presence of light quanta and requires Mn^{++} and Cl^- ions as catalyst for water oxidising.

$$4H_2O \xrightarrow{Mn^{++}Cl^-} 4(OH)^- + 4H^+$$

Then H radicle forms water and O_2 as a by product

$$4OH \longrightarrow 2H_2O + O_2 \uparrow$$

12. (b) Emerson and Arnold proved the existence of light and dark reaction by flashing of light experiment in photosynthesis.

Photosynthetic apparatus

1. (a) In Etiolation, chlorophyll (green) converts in protochlorophyll (yellow) in dark, etiolin hormone is formed due to which plants become elongated.

$$\underset{\text{(green)}}{\text{Chlorophyll}} \underset{\text{Light}}{\overset{\text{Dark}}{\rightleftharpoons}} \underset{\text{(yellow)}}{\text{Protochlorophyll}} + 2H$$

2. (b) Photosynthesis by plants is most vital process for the existence of life on earth because photosynthesis helps to maintain the equilibrium position of O_2 and CO_2 in the atmosphere. It purifies the air and synthesize food for all living beings.

4. (b) $6CO_2 + 12H_2O \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} C_6H_{12}O_6 + 6O_2 + 6H_2O$.

5. (b) When photon of light energy falls on chlorophyll molecule, one of the electrons pair from ground or singlet state passes into higher energy level called excited singlet state.

7. (b) The main function of chloroplast is photosynthesis, in which radiant energy of sun is converted into chemical form of energy (ATP), which is utilized by all living organisms to perform their life activities.

8. (a) The addition of phosphate group to ADP and AMP called phosphorylation.

$$ADP + iP \longrightarrow ATP$$

By this process ATP is formed which is used in dark reaction.

9. (b) Photosynthesis reaction shows that "formation of carbohydrates from CO_2 and H_2O by illuminated green cells of plants, O_2 and H_2O are the bye products.

15. (c) 90% of total photosynthesis is carried out by aquatic plants, chiefly algae (80% in oceans and 10% in fresh water). 10% of total photosynthesis is performed by land plants.

17. (b) ATP is formed during photophosphorylation after this reaction NADPH$_2$ and ATP move in dark reaction it is known as assimilatory power.

19. (b) $CO_2 + 2H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light energy}} (CH_2O)_n + H_2O + O_2 \uparrow$

22. (b) Rubisco constitutes 16% of chloroplast protein. It is the most abundant protein on this planet.

23. (d) Only 1-4% light is utilized in photosynthesis. In general rate of photosynthesis is more in intense light than diffused light.

24. (d) Photosynthesis is an oxidation reduction process where H_2O is oxidized by photolysis into O_2 and CO_2 is reduced into carbohydrates.

26. (a) Arnon (1956) used the term 'Assimilatory powers' for ATP and NADPH$_2$. (NADPH$_2$ alone is called reducing power).

29. (a) Sugarcane is C_4 plant. The chloroplasts in C_4 leaves are dimorphic (Two morphologically distinct types). The chloroplasts of bundle sheath cells contain starch grains but lack grana. The mesophyll cells on the other hand, contain normal type of chloroplasts.

32. (b) Because CO_2 is utilized in photosynthesis process by plants.

34. (c) Burning of sugar, respiration in plants and heating of limestone is responsible for the liberation of CO_2 but in photosynthesis green plants take in CO_2 and release O_2 thus purifying the air.

35. (b) Park and Biggins (1964) gave the term quantasome for photosynthetic units is equivalent to 230 chlorophyll molecules.

36. (b) ATP (adenosine triphosphate) is called energy currency of cells. ATP is energy rich compound where energy is present in terminal pyrophosphate bonds.

37. (d) Light, chlorophyll, CO_2 and water all are essential in photosynthesis. In photosynthesis process energy rich compounds like carbohydrates are synthesized from simple inorganic compounds like carbon dioxide and water in the presence of chlorophyll and sunlight with liberation of O_2.

Light reaction/Pigments

1. (c) The splitting of water during photosynthesis is called photolysis. *Mn* and *Cl* plays important role in photosynthesis specially light reaction of photosynthesis in splitting of water.

7. (b) Chlorophyll-*a* is widely distributed in green plant and it is also called primary photosynthetic pigment and universal photosynthetic pigment.

8. (a) The chloroplast pigment are fat soluble and are located in the lipid part of the thylakoid membranes.

10. (d) Xanthophylls are yellow coloured carotenoid also called Xanthols or carotenols.

12. (c) Wavelength occur in red part of the spectrum is 650-760 *nm*.

33. (b) Non cyclic photophosphorylation involved both PS-I and PS-II. Flow of electrons is unidirectional. Here electrons are not cycled back and are used in the reduction of NADP to $NADPH_2$.

37. (c) Chl.–a 700 or P_{700} is the reaction centre of PS-I.

38. (c) The colours of leaves is modified in certain plants due to the presence of purple pigment called anthocyanins. Anthocyanins are soluble in water, hence they occur in solution in the water of the cells.

41. (a) Chlorophyll a is widely distributed in green algae and higher plants.

49. (c) During light reaction energy from sunlight is absorbed and converted into chemical energy which is stored in ATP and NADPH + H^+.

50. (b) Core metal of chlorophyll is *Mg*. When central *Mg* is replaced by *Fe*, the chlorophyll becomes a green pigment called "cytochrome" which is used in photosynthesis.

52. (c) Phosphate is coupled with ADP to produce ATP using light energy during photosynthesis.

53. (a) Cytochromes are systems of electron-transferring proteins, with iron-porphyrin or copper-porphyrin as prosthetic groups.

55. (c) Photolysis means splitting of water molecules to release oxygen. This occurs in photosynthesis, *i.e.*, Photosystem–II.

56. (a) Chlorophyll is soluble in organic solvents like alcohol, acetone etc.

57. (a) Green plants and algae use two types of photosystems, PS-I with chl. P_{700} in its reaction centre and PS-II with P_{680} in its reaction centre. The two photosystems are linked by a chain of electron carriers. Light excites P_{680} of PS-II to activated P_{680}.

58. (a) This non-cyclic photophosphorylation is also known as Z-Scheme (because of shape of path of electron – flow) and this was given by Hill and Bendall (1960).

61. (a) The reaction centers of PS–I and PS–II can be denoted as P_{700^+} and P_{680^+} respectively. Positively charged reaction centers act as attractants for electrons.

63. (c) The important pigments of this system are chlorophyll *a* 670, chlorophyll *a* 683, chlorophyll *a* 695, P_{700}. Some physiologist also include carotenes and chlorophyll *b* in pigment system I. P_{700} act as the reaction centre.

64. (c) Light energy brings about changes in *Mn* (Mn^{2+}, Mn^{3+}, Mn^{4+}) which helps in removing electrons from OH^- component of water forming oxygen.

65. (a) Robert Hill (1939) first of all showed that if chloroplasts extracted from leaves of *stellaria media* and *Lamium album* are suspended in a test tube containing suitable electron acceptor *e.g.*, potassium ferrooxalate and potassium ferricyanide, O_2 is released due to photochemical splitting of water.

69. (b) During light reaction not only reduced NADP is formed and O_2 is evolved but ATP is also formed. This formation of high energy phosphates (ATP) is dependent on light hence called photophosphorylation.

71. (a) Non cyclic photophosphorylation involves both *PS-I* and *PS-II*. The process begins with the absorption of light energy by *PS-II*. As light energy is absorbed, $4e^-$ become excited from chlorophyll –*a* at the reaction centre. The $4e^-$ released by these molecules are accepted by an electron – acceptor – substance. The other effect of this event is that photolysis of water is induced. The chlorophyll-*a* molecules in *PS-II* act as strong oxidising agent. As described earlier, 4 molecules of H_2O are thus decomposed through light-induced-energy. The $4H^+$ *ions* become associated with 2 *NADP*. The 4 OH^- *ions* are associated with the release of oxygen. The four electrons ($4e^-$) released from 4 OH^- are received by chlorophyll-*a* molecules at reaction-centre of *PS-II*.

72. (b) The photosystem-II (Reaction centre of P-680) extracts an e^- from water returning to its unexcited state. The removal of four e^- from two molecules of water requires 4 quanta of light to fall on PS-II and leads to the production of $4H^+$ ions and one molecule of O_2.

79. (c) The absorption spectrum of chlorophyll *a* and chlorophyll *b* indicate that these pigments mainly absorb blue and red lights. Action spectrum shows that maximum photosynthesis takes place in blue and red regions of spectrum.

80. (b) The figure denotes non-cyclic photophosphorylations that involves both *PS-I* (reaction centre-700) and *PS-II* (reaction centre-680). The electrons released from *PS II* is not cycled back but is transported to *PS-I* through a series of chemical compounds. Before reaching *PS-I*, the electrons pass through plastocyanin.

Dark reaction

1. (c) Dark reaction was first of all established by Blackman that's why it is called Blackman's reaction.

7. (d) Dark reaction takes place in bundle sheath (because RuBISCO present in stroma of chloroplast of bundle sheath).

12. (c) A- Fixation of CO_2 by PEPCO
B- Decarboxylation
C- Regeneration

13. (a) Ribulose 1, 5–diphosphate carboxylase enzyme is first enzyme of Calvin cycle convert Ribulose-1, 5 diphosphate into 3–phosphoglyceric acid.

14. (b) During photosynthesis PGA is reduced by NADP. 2H into phosphoglyceraldehyde.

16. (a) Calvin cycle occurs in the stroma of chloroplasts where the products of light reaction (assimilatory power NADP.2H + ATP) are used to form CO_2 to carbohydrate and it has enzymes essential for fixation of CO_2 and synthesis of sugar.

17. (b) The new name of dark reaction is carbon assimilation, in which CO_2 gas reacting with H_2O (liquid) synthesizes solid glucose.

18. (a) In C_3 cycle, in presence of rubisco (*RuBP* carboxylase) CO_2 combines with ribulose 1, 5–bisphosphate (acceptor molecule) to form 3-phosphoglyceric acid or 3–PGA which is the first stable product of carbon reduction cycle.

23. (b) As Calvin cycle takes only one carbon (as CO_2) at a time. So it takes six turns of the cycle to produce a net gain of one hexose or glucose.

25. (c) Reductive carboxylation start with a 5 carbon sugar ribulose – 5 phosphate. 6 mol of this sugar react with 6 mol of ATP (produced in light reaction) to form 6 mol of RuBP and 6 mol ADP

$$\text{Ribulose - 5 phosphate} \xrightarrow{\text{Phosphopentokinase}} \text{Ribulose 1, 5–biphosphate} + 6\text{ADP}$$

29. (c) Ribulose 1, 5–diphosphate (also known as ribulose biphosphate) a phosphorylated 5 carbon sugar (pentose sugar) it is first attached with CO_2 in photosynthesis.

31. (b) Calvin cycle is divided into three distinct phase but carboxylation occur only one time.

C_4/CAM/Photorespiration

1. (d) This pathway was first reported in members of family gramineae (grasses) like sugarcane, maize etc. More than 300 species belong to dicots and the rest belong to monocots. There are no known C_4 gymnosperms, bryophytes or algae.

9. (a) Photorespiration is a process of respiration which takes place in the presence of light and in chloroplasts only. In this process, first of all *RuBP* is oxygenated in presence of O_2. Then, 1 molecule of a 2-C phosphoglycolate and 1 mol. of a 3C *PGA* are formed from it. The *PGA* molecule is used in the Calvin cycle. Phosphoglycolate is dephosphorylated and glycolate is formed. Glycolate diffuses out of chloroplast and enters the organelle called peroxisome. Here it is oxidized and becomes glyoxylate. Glyoxylate is used in synthesis of glycine.

11. (d) Photorespiration is quite different from respiration as no ATP or NADH are produced, the energy released being lost as heat. Moreover, the process is harmful to plants because as much as half the photosynthetically fixed CO_2 (in the form of RuBP) may be lost into the atmosphere through this process.

18. (a) One of the basic features of C_4 plants is that CO_2 is trapped by a CO_2 acceptor, phosphoenol pyruvic acid present in the (PEP) chloroplasts of mesophyll cells of these leaves, leading to the formation of a 4-C compound oxaloactic acid.

19. (b) In Hatch-Slack pathway, first product of CO_2 fixation is a 4 carbon compound, oxaloacetic acid hence they are called C_4 plants. This acid is converted to another 4-C acid, the malic acid.

20. (c) Basic feature of C_4 plants is the occurrence of "Kranz" (German term meaning halo or wreath) type of leaf anatomy. The vascular bundles, in C_4 leaves are surrounded by a layer of bundle sheath cells that contain large number of chloroplasts. The chloroplast in C_4 leaves are dimorphic (Two morphologically distinct type).

23. (d) Photorespiration is absent in C_4 plants due to presence of kranz anatomy.

27. (b) These are succulent plants with water storing cells.

28. (b) In C_4 plants agranal chloroplast occur in bundle sheath.

29. (a) In C_4 plants initial CO_2 fixation occurs in Mesophyll cells. As a result malic acid is formed. This malic acid is transferred in Bundle sheath chloroplast where it is decarboxylated.

30. (c) C_3 and C_4 cycle both occurs in panicum milioides hence it stand intermediate between C_3 and C_4 plants.

32. (b) C_4 plants utilise solar energy most efficiently. Because photosynthesis rate is very high in C_4 plants e.g., Sugarcane, maize etc.

33. (a) In crassulacean acid metabolism (CAM) plants large amount of acid like malic acid etc. are synthesized at night. The stomata remain closed the day time but remain open at night. CAM plants are succulent drought evading plants.

38. (b) In CAM plants there is no kranz anatomy, but there occurs dark acidification, *i.e.*, during night malic acid is formed. This malic acid breaks up into CO_2 and pyruvic acid in day time and CO_2 released is utilized in C-3 cycle.

40. (b) In 1965 kortschak, Hart and Burr working with $C^{14}O_2$ on sugarcane leaves found C_4 dicarboxylic acid, malate and aspartate to be the major labelled products in very short periods of photosynthesis. This observation was confirmed by M.D. Hatch and C.R., Slack in 1967. The Hatch-slack pathway, as this alternative CO_2 fixation is called, has been found to occur in tropical and sub-tropical grasses and some dicotyledons.

46. (a) In C_4 plants poor supply of CO_2. Because there is a internal supply of CO_2. So these plants can survive in poor CO_2 conditions.

47. (c) Phosphoenol pyruvic acid carboxylase fixed CO_2 in sugarcane. Due to this enzyme PEP + CO_2 converted into oxaloacetic acid.

48. (d) Photorespiration is absent in C_4 plants.

50. (a) PCO or photorespiration is also called C_2 cycle as there is synthesis of 2-carbon compound.

51. (c) Three conditions are required for photorespiration (1) High O_2 concentration (2) Low concentration of CO_2 (3) High light intensity. During photorespiration oxygenation takes place firstly.

52. (d) Glyoxylate is used to form glycine, glycine enters in mitochondria where two glycine molecules give rise to one molecule of serine and one CO_2.

53. (b) Two times carboxylation occur in C_4 cycle, first carboxylation is done by phosphoenole pyruvate and second in bundle sheath cell by Ribulose 1, 5 biphosphate.

54. (b) Bundle sheath chloroplast larger in size, lack grana (Agranal chloroplast) and contain starch grains. Mesophyll chloroplast small in size, contain grana and lack starch grains.

57. (b) The process of photorespiration involves the involvement of chloroplast, peroxysome and mitochondria.

Bacterial photosynthesis

2. (b) Chemosynthetic bacteria are able to manufacture all their organic food from inorganic raw material in the absence of light.

$$6CO_2 + 24\,[H] \xrightarrow{\text{Enzymes/Energy}} C_6H_{12}O_6 + 6H_2O$$

3. (b) Like cyanobacteria, algae, autotrophic plants and photoautotrophic bacteria also use light energy for reducing CO_2 to organic compounds but water is never used as a source of electrons in bacteria. Hence, oxygen is never evolved during bacterial photosynthesis.

4. (a) The bacterial pigments are however not contained in chloroplast but are present in structures called chromatophores .

5. (a) $CO_2 + 2H_2S \xrightarrow{\text{Sunlight}} (CH_2O) + 2S + H_2O + \text{Energy}$

6. (d) Photosynthetic bacteria absorb (850-950*nm*) infra-red wavelength.

7. (c) *Leptothrix*, is a iron bacteria oxidise $\underset{\text{(Ferrous)}}{Fe^{2+}} \longrightarrow \underset{\text{(Ferric)}}{Fe^{3+}}$ + chemical energy.

8. (c) Green bacteria contain green pigment bacterioviridin (chlorobium chlorophyll), which absorbs red light, showing maximum absorption in the region of 650-660.

10. (d) The photosynthetic bacteria use inorganic electron donor such as H_2S, H_2, sulphur compound etc. They contain bacterio-chlorophyll but chlorophyll a is absent.

11. (c) Purple non-sulphur bacteria contain purple pigment bacteriochlorophyll and carry on photosynthesis in presence of simple organic compounds like organic acids and alcohol *e.g.*, *Rhodospirillum rubrum.*

$$2CH_3CHOHCH_3 + CO_2 \xrightarrow{\text{Sunlight}} (CH_2O) + 2CH_3COCH_3 + H_2O$$

13. (c) The oldest micro-fossils discovered so far are that of photosynthetic cyanobacteria that appeared 3.3 to 3.5 billion year ago.

Factors affecting photosynthesis

1. (c) During light reaction of photosynthesis O_2 release as a result of photolysis of water. DCMU is a photosynthetic inhibitor which inactivates the PS-II and inhibit the Hill reaction.

3. (d) Law of limiting factor was proposed by Blackman in 1905. He stated 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 slowest factor.

4. (b) The maximum temperature at which photosynthesis can occur is 55°C in some desert plants and 75°C for hot spring algae.

5. (a) German scientist Warburg (1920) reported in *chlorella* alga that high O_2 level inhibit rate of photosynthesis and this inhibition of photosynthesis by increased O_2 concentration is called Warburg's effect.

6. (b) Rate will be increased due to the ejection of CO_2 from $NaHCO_3$.

7. (d) Blue and red regions of the light spectrum are the most effective in photosynthesis. Blue wavelengths of light carry more energy while red wavelengths have lesser energy. Therefore, the most efficient wavelengths of light effective in photosynthesis are those of light.

8. (b) Compensation point is existed in morning and evening time. At this time the rate of photosynthesis (intake of CO_2) and rate of respiration (outcome of CO_2) is equal. At this point no exchange of CO_2 is possible through stomata. The unit is lumen.

11. (b) Because blue colour comes first in spectrum light.

12. (c) R. Emerson and C.M. Lewis (1943) observed that the quantum yield of photosynthesis decreased towards the far red end of the spectrum (680*nm* or longer).

14. (c) Normal conc. of CO_2 in atmosphere is 0.03% (*i.e.*, 300 *ppm*). By increases but after that it decreases.

15. (a) Because light reaction is much faster than dark reaction, so in continuous light there is accumulation of ATP and $NADPH_2$ and hence reduction in rate of photosynthesis but in discontinuous light, ATP and $NADPH_2$ formed in light are fully consumed during dark in reduction of CO_2 to carbohydrates.

22. (c) If the amount of oxygen in the atmosphere decreases then photosynthesis will increase in C_3 cycle (wheat) and no change in C_4 cycle.

Critical Thinking Questions

4. (b) Normally plants utilize sunlight but marine algae also use moon light, photosynthesis even occur in electric light.

6. (c) RuBP-oxygenase is a form of Rubisco, which constitutes 16% of chloroplast protein. It is the most abundant protein on this planet.

7. (a) Cytochromes – Hence proteins (iron containing proteins) serving as electron carriers in respiration photosynthesis and other oxidative reduction reactions.

8. (b) Reduction of carbon, anabolised organic compound will give ATP during respiration. Photosynthesis is an anabolic and endothermic reaction. It is a mechanism of synthesis of food.

9. (b) Lichen's can photosynthesize at very low temperature. i.e., – 24°C.

12. (a) Chlorophyll a occurs in all except photoautotrophic bacteria, *i.e.*, all oxygenic photoautotrophs.

13. (c) Chlorophyll a is bluish-green with empirical formula of $C_{55}H_{72}O_5N_4Mg$.

16. (b) Purple sulphur bacteria and non-sulphur bacteria contain bacterio-chlorophyll, which is having 2H-atoms more than chl. a and it absorbs 850-950 *nm* (infra-red) wavelength of light.

18. (d) C_4 plants mostly in monocot plants (*Artiplex*, sugarcane, maize, cyperus) and some dicots (*Amaranthus*).

21. (c) In carboxylation Ribulose – 1, 5 – biphosphate (RuBP) (= Ribulose diphosphate) acts as CO_2 acceptor and 6 mols of RuBP react with 6 mols of CO_2 and 6 mols of water giving rise to 12 mols of 3-phosphoglyceric acid.

23. (d) 3 molecules of CO_2 combine with 3 molecules of RuBP to produce 3 molecules of an unstable 6-C compound which immediately breaks down into molecules of 3-phosphoglyceric acid.

28. (d) Chromatophores contain pigments and they are found in blue green algae for photosynthesis.

Assertion and Reason

1. (b) C_4 pathway found in tropical angiosperms and called as Hatch and Slack cycle. Here CO_2 is fixed by 3C compound (phosphoenol pyruvate, PEP).

2. (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.

3. (c) Anthocyanin pigment, present in cell sap of vacuole. It is responsible for the colouration of flower parts. It is not a photosynthetic pigment.

4. (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.

5. (a) Small quantity of oxygen is essential for photosynthesis except in some anaerobic bacteria. The inhibition of photosynthesis at high O_2 levels may be due to (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, (iii) It converts RuBP carboxylase to RuBP-oxygen. At a very high oxygen content the rate of photosynthesis begins to decline in all plants. The phenomenon is called Warburg effect (reduction due to photorespiration).

6. (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.

Photorespiration is a wasteful process as it works to undo the act of photosynthesis in C_4 plants. No energy rich compound is produced in this process. When temperature increase more and more photosynthetically fixed carbon is lost by photorespiration thus reducing the efficiency of C_3 plants.

7. (c) CAM plants do not exhibit the structural compartmentation (C_3 and C_4 cycles taking place in different cells) of conventional C_4 plants. CAM plants fix CO_2 at night because their stomata are open at night and closed during the day.

8. (b) Plants that utilize primarily *RuBP* to fix CO_2, which results in the formation of the three-carbon compound 3-PGA, are called C_3 plants. Hatch and Slack proposed a new pathway of CO_2 fixation via the carboxylation of PEP. Because the products are four-carbon compounds, plants exhibiting this pathway are referred to as C_4 plants.

9. (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.

10. (d) The grana stacks of membranes are enriched in PS II and LHC (Light harvesting centre), while there is little ATP synthetase. On the other hand, a fraction of stroma thylakoids is rich in PS I and ATPase and poor in PS II and LHC.

11. (b) In case of cyclic photophosphorylation, the electron, while passing between ferredoxin and plastoquinone and/or over the cytochrome complex the electron loses sufficient energy to form ATP from ADP and inorganic phosphate.

12. (b) The synthesis of ATP *via* electron flow through the ETS, with oxygen as the terminal electron acceptor, is known as oxidative phosphorylation and takes place in mitochondria. In contrast to the oxidative phosphorylation of mitochondria, O_2 is not used in photophosphorylation of chloroplasts and $NADP^+$ is last electron acceptor.

13. (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.

14. (e) Malic acid or aspartic acid is translocated to bundle sheath cells through plasmodesmata. Inside the bundle sheath cells they are decarboxylated (and deaminated in case of aspartic acid) to form pyruvate and CO_2. CO_2 is again fixed inside the bundle sheath cells through Calvin cycle. RuBP of Calvin cycle is called secondary or final acceptor of CO_2 in C_4 plants.

15. (e) The overall equation of photosynthesis is

$$CO_2 + 2H_2O + n(h\nu) \rightarrow (CH_2O) + H_2O + O_2.$$

The standard free-energy change for the synthesis of hexose from CO_2 and H_2O is $\Delta G^\circ = +686\ kcal$. As six molecules of CO_2 is involved to form one molecule of hexose, the energy input per CO_2 molecule will be 114 *kcal*.

16. (a) The energy balance of photosynthesis is :

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

which represents a storage of 686,000 calories per mole. This energy is provided by a total of 12 *NADPH* and 18 ATP molecules, which represent 750,000 calories. The efficiency reached by the PCR cycle is thus as high as 90% (686/750 × 100 = 90%).

17. (e) Plants are grouped into two groups depending upon their inability or ability to tolerate high light intensity-shade plants (Sciophytes) and sun plants (Heliophytes). Sciophytes grow in poorly illuminated conditions as below the canopy of tall plants in seek of shade. Heliophytes grow in the open.

18. (e) Less than 1% of the total water absorbed is utilized in photosynthesis. The rest is lost in transpiration. Even a slight increase in transpiration reduces the leaf hydration that cuts down photosynthesis by causing stomatal closure and hence decreased CO_2 absorption, loss of leaf turgidity, reduced absorption of solar radiations and decrease enzymatic activity.

Photosynthesis in Higher Plants

SET Self Evaluation Test

1. In C_3 cycle for the fixation of every CO_2 molecule, the reduction and regeneration steps require **[AMU (Med.) 2009, 10; CPMT 2010; Kerala PMT 2011]**
   (a) 3 ATP and $NADPH_2$ (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 $NADPH_2$

2. "Impure air is purified in the presence of light and green plants" was first said by
   (a) De Saussure (b) Priestley
   (c) Van Helmont (d) Ingenhousz

3. From which of the following photosynthetic autotrophs receive their energy **[WB JEE 2008]**
   (a) Heat (b) Inorganic chemicals
   (c) Organic chemicals (d) Light

4. During cyclic electron transport, which one of the following is produced **[J & K CET 2010]**
   (a) ATP only (b) Erythrose
   (c) $NADH_2$ (d) None of these

5. For each molecule of glucose formed in plants, the number of molecule of ATP and $NADPH_2$ required are respectively **[MH CET 2006]**
   (a) 12 and 18 (b) 18 and 12
   (c) 15 and 10 (d) 3 and 22

6. How many molecules of glycine is required to release one CO_2 molecule in photorespiration **[AFMC 2004]**
   (a) One (b) Two
   (c) Three (d) Four

7. The process in which excess energy is lost by light waves is called **[JIPMER 2002]**
   (a) Fluorescence (b) Photophosphorylation
   (c) Photolysis (d) Photooxidation

8. With respect to compensation point, which of the following is true for C_3 and C_4 plants **[GUJCET 2007]**
   (a) Compensation points of C_3 and C_4 plants are equal
   (b) Compensation point of C_3 plant is higher than C_4 plant
   (c) Compensation point of C_4 plant is higher than C_3 plant
   (d) None of the above

9. A pigment which absorbs red and far-red light is **[CBSE PMT 1997]**
   (a) Phytochrome (b) Carotene
   (c) Cytochrome (d) Xanthophyll

10. Which of the following is formed during photorespiration **[Kerala PMT 2011]**
    (a) Sugar (b) Phosphoglycolate
    (c) $NADPH$ (d) ATP
    (e) Oxaloacetate

11. Which pigment is absent in chloroplast

    Or

    Which one of the following does not play any role in photosynthesis **[DUMET 2010]**
    (a) Xanthophyll (b) Anthocyanin
    (c) Chlorophyll 'a' (d) Carotene

12. Which one of the following statements is correct for chlorophyll a **[MP PMT 1995]**
    (a) Chlorophyll a is found more than chlorophyll b in leaves of most plants
    (b) Chlorophyll a and b are found in equal proportion in leaves of most plants
    (c) Chlorophyll a is found less than chlorophyll b in leaves of most plants
    (d) Chlorophyll b is found ten fold more than chlorophyll a in leaves of most plants

13. The C_4 plants are different from C_3 plants with reference to the **[AFMC 1997]**
    (a) Substance that accept CO_2 in carbon assimilation
    (b) Type of end product of photosynthesis
    (c) Number of ATP that are consumed in preparing sugar
    (d) Types of pigments involved in photosynthesis

14. Synthesis of food in C_4 pathway occurs in chlorophyll of **[KCET 2007]**
    (a) Guard cells (b) Bundle sheath
    (c) Spongy mesophyll (d) Palisade cells

15. NH_3 Release from **[MP PMT 2007]**
    (a) Photorespiration (b) Dark respiration
    (c) CAM (d) All of these

16. Which of the following fixes CO_2 in carbohydrates **[BVP 2003]**
    (a) Rhodospirillium (b) Nitrobacter
    (c) Rhizobium (d) Bacillus

17. Liberation of O_2 when green cells in water are exposed to sunlight in the presence of suitable acceptor is called **[KCET 2007]**
    (a) Arnon's reaction
    (b) Emerson's enhance effect
    (c) Blackmann's reaction
    (d) Hill's reaction

18. Which of the following is capable of performing photosynthesis at high temperature *i.e.* at 50° C
    (a) *Opuntia* (b) Mango
    (c) Potato (d) None of the above

19. The first product of CO_2 fixation in Hatch and Slack (C_4) cycle in plants is **[KCET (Med.) 2001, 10]**

(a) Formation of oxaloacetate by carboxylation of phosphoenol pyruvate (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 phosphoenol pyruvate (PEP) in the mesophyll cells

20. Optimum temperature for Photosynthesis is **[MP PMT 2011]**

(a) 10 – 15°C (b) 20 – 25°C

(c) 25 – 30°C (d) 35 – 40°C

Answers and Solutions

1	a	2	b	3	d	4	a	5	b
6	b	7	d	8	b	9	a	10	b
11	b	12	a	13	a	14	b	15	a
16	a	17	d	18	a	19	d	20	c

2. (b) Priestley demonstrated that green plants purify the foul air (*i.e.*, phologiston) produced by burning of candle and convert it into pure air (*i.e.*, Dephologiston).

5. (b) During formation of one glucose molecule in plant 3 ATP required for fixation of one CO_2 molecule. Thus in plants required 18 ATP and 12 $NADPH_2$.

6. (b) There is two molecule of glycine used and interact to form one molecule each of serine CO_2 and NH_3.

2Glycine$+H_2O+NAD \rightarrow$ Serine $+ CO_2+NH_3+NADP$

7. (d) Certain cell constituents are oxidized by oxygen into CO_2 as known as photo-oxidation.

8. (b) Under the conditions of sufficient light and low CO_2 concentration, the rate of photosynthesis equals the rate of respiration (respiration and photorespiration together) in any plant. This concentration of atmospheric CO_2 absorbed from the atmosphere equals the amount of CO_2 at which the photosynthesis and respiration become balanced is called - CO_2 compensation point. This compensation point is achieved when the amount of CO_2 absorbed from the atmosphere equals the amount of CO_2 released through plant respiration. However is necessary that available light does not become a limiting factor. At this point, effective photosynthesis becomes nil. The compensation point is higher in C_3 plants in relation to that in C_4 plants as rate of photorespiration is high in C_3 plants.

9. (a) Phytochrome is a proteinaceous pigment found in low concentrations in most plant organs. It exists in two forms P $_{\text{sub FR}}$ (or P $_{\text{sub 660}}$) has an absorption peak at 660*nm* (red light) and the other P $_{\text{sub FR}}$ (or P $_{\text{sub 730}}$) at 730*nm* (far-red).

11. (b) Anthocyanin pigment is absent in chloroplast. It is present in cell sap of vacuole and not take any part in photosynthesis.

12. (a) Chlorophyll *a* is found in all autotrophic plants except the photosynthetic bacteria.

13. (a) Here in C_4 plants, CO_2 acceptor molecule is PEP (Phosphoenol pyruvate) and in C_3 plant CO_2 molecule is RuBP (ribulose 1-5 biphosphate).

16. (a) Rhodospirillum bacteria completed their photosynthesis by bacteriochlorophyll *b*. These are found in mud and stagnant water.

18. (a) For desert plants like *Opuntia* required 50°C temperature for photosynthesis.

19. (d) CO_2 taken from the atmosphere is accepted by phosphoenolpyruvic acid (PEP) present in the chloroplast of mesophyll cells of these leaves, leading to the formation of a 4-C compound, oxaloacetic acid (OAA).

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