PHOTOSYNTHESIS

INTRODUCTION

All living organisms require continuous use of energy to carry out their different activities. This energy directly or indirectly comes from sun.

Photosynthesis is the only process on earth by which solar energy is trapped by autotrophic organisms and converted into food for the rest of organisms.

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".

Earlier, photosynthesis was considered to be reverse of respiration, i.e.,

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

Above reaction gives an idea that O_2 comes from CO_2. But **Ruben** and **Kamen** (1941) experimentally verified that source of liberated O_2 in photosynthesis is H_2O, not CO_2.

Thus, overall reaction can be corrected as given below :

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

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 an anabolic and endothermic reaction. Photosynthesis helps to maintain the equilibrium position of O_2 and CO_2 in the atmosphere.

5.1 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 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 presence of light. He also showed that the rate of O_2 evolution depends upon the rate of CO_2 consumption.
- **Lavoisier** (1783) identified the pure air (*i.e.,* dephlogiston) as oxygen (O_2) and noxious air (*i.e.,* Phlogiston) produced by the burning of candle as carbon dioxide (CO_2).
- **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.
- **Pelletier** and **Caventou** (1818) discovered chlorophyll. It could be separated from leaf by boiling in alcohol.
- **Dutrochet** (1837) showed the importance of green pigment chlorophyll in photosynthesis.
- **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.
- **J.C. Maxwell** (1864) developed 'wave model of light', leading to recognition that light is source of energy in photosynthesis.
- **Theodore Engelmann** (1884, 88) showed that chloroplast as the site of photosynthesis in the cell and also discovered the role of different wave lengths of light on photosynthesis and plotted the action spectrum.
- **F.F. Blackmann** (1905) proposed the 'law of limiting factor' and also discovered two steps of photosynthesis *i.e.,* light dependent and temperature independent steps and a light independent and temperature dependent step.

He proved that photosynthesis is a photochemical and biochemical reaction. Photochemical reaction is **light reaction** and biochemical reaction is **dark reaction** or carbon dioxide fixation.

- **Willstatter** and **Stoll** (1912) studied structure of photosynthetic pigments.
- **Warburg** (1919) performed flashing light experiment using green alga-*Chlorella* as a suitable material for the study of photosynthesis.
- **Van Niel** (1931) demonstrated that some bacteria use H_2S instead of H_2O in the process of photosynthesis.
- **Emerson and Arnold** (1932) proved the existance of light and dark reactions by flashing of light experiment in photosynthesis.

- **Robert Hill** (1937) demonstrated photolysis of water by isolated chloroplast in the presence of suitable electron acceptor.
- **S. Ruben** and **M. Kamen** (1941) used heavy isotope ^{18}O and confirmed that oxygen evolved in photosynthesis comes from water and not from CO_2.
- **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.
- **Emerson, Chalmers** and **Cederstrand** (1957) discovered Emerson effect.
- **Hill** and **Bendall** (1960) proposed Z scheme and suggested that two photosystems operate in series.
- **Arnon** (1961) discovered photophosphorylation and gave the term 'assimilatory powers'.
- **Peter Mitchell** (1961) proposed chemi-osmotic coupling hypothesis.
- **Kortschak** (1965) discovered the formation of C_4 dicarboxylic acid in sugarcane leaves.
- **Hatch** and **Slack** (1966) reported the C_4 pathway for CO_2 fixation in certain tropical grasses.
- **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.

5.2 Photosynthesis in higher plants

(1) **Chloroplast-The site of photosynthesis :** The most active photosynthetic tissue in higher plants is the mesophyll of leaves. Mesophyll cells have many chloroplast. Chloroplast are present in all the green parts of plants and leaves. There may be over half a million chloroplasts per square millimetre of leaf surface. In higher plants, the chloroplasts are discoid or lens-shaped. They are usually 4-10μm in diameter and 1-3μm in thickness.

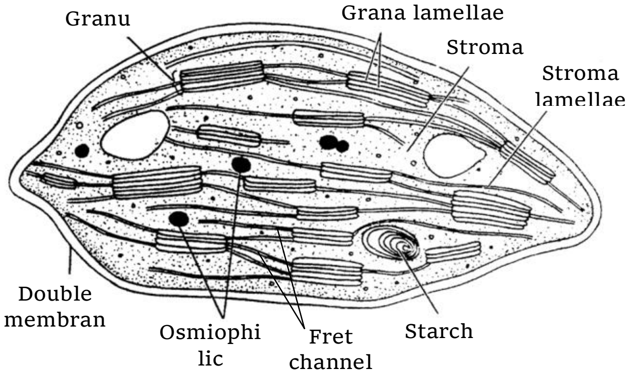


Fig : Internal structure of a typical chloroplast (Diagrammatic representation of sectional view)

These are double membrane-bound organelles in the cytoplasm of green plant cells. Chloroplast has two unit membranes made up of lipoprotein. Outer membrane of chloroplast is permeable and an inner one impermeable to protons. Inside the membranes is the proteinaceous ground substance called **stroma**, which contain a variety of particles, osmiophilic droplets, dissolved salts, small double stranded circular DNA molecules and 70S type ribosomes along with various enzymes. Inside the stroma is found a system of chlorophyll bearing double-membraned sacs thylakoids or lamellae.

Thylakoids are flattened sacs arranged like the stacks of coins. One stack of thylakoids is called **granum**. Different grana are connected with the help of tubular connections called **stroma lamellae** or

frets. Grana are the sites for light reaction of photosynthesis and consist of photosynthetic unit 'quantasomes' (Found in surface of thylakoids). 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 is equivalent to 230 chlorophyll molecules.

(2) **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. 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 : (i) Chlorophylls and (ii) Carotenoids

The other photosynthetic pigments present in some algae and cyanobacteria are phycobilins.

(i) **Chlorophylls :** The chlorophylls, the green pigments in chloroplast are of seven types *i.e.*, chlorophyll *a, b, c, d, e*, bacteriochlorophyll and bacterioviridin.

Of all, only two types *i.e.*, chlorophyll *a* and chlorophyll *b* are widely distributed in green algae and higher plants.

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**.

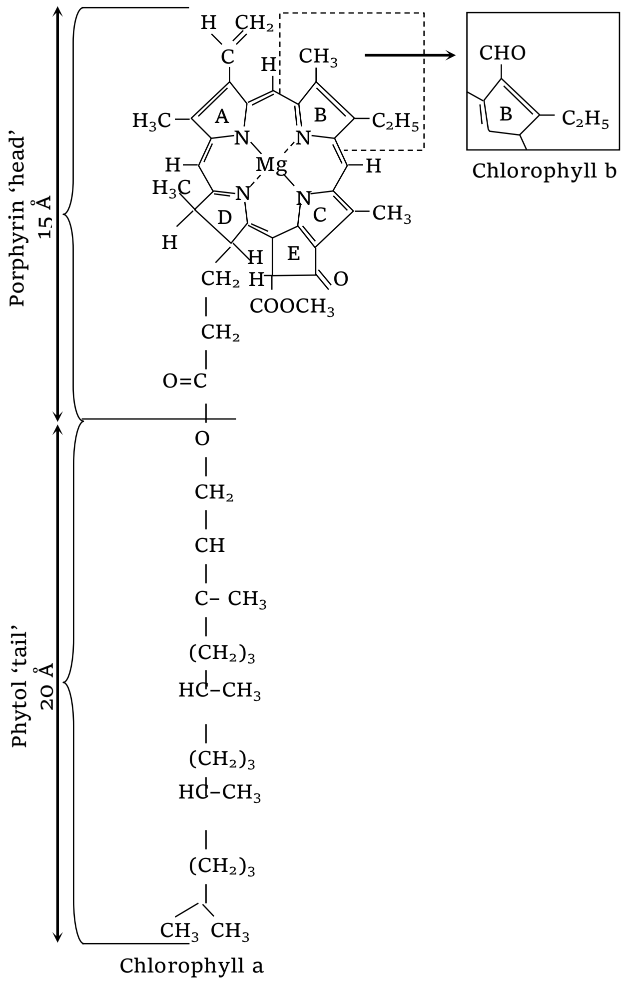


Fig : Chemical structure of chlorophyll a and b molecules

Chlorophyll *a* is blue black while chlorophyll *b* is green black. Both are soluble in organic solvents like alcohol, acetone etc. chlorophyll *a* appears red in reflected light and bright green in transmitted light as compared to chlorophyll *b* which looks brownish red in reflected light and yellow green in transmitted light. Chlorophyll is a green pigment because it does not absorb green light (but reflect green light) Chlorophyll *a* possesses — CH_3 (methyl group), which is replaced by — *CHO* (an aldehyde) group in chlorophyll *b*. 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 is linked together by **methine** (CH=) groups forming a ring system. Each pyrrole ring is made up of four carbon and one nitrogen. The porphyrin head bears many characteristic side groups at many points. Different side groups are indicative of various types of chlorophylls.

Phytol tail is made up of 20 carbon alcohol attached to carbon 7 position of pyrrole ring IV with a propionic acid ester bond. The basic structure of all chlorophyll comprises of porphyrin 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.

Chlorophyll synthesis is a reduction process occurring in light. In gymnosperm seedlings, chlorophyll synthesis takes place in darkness in presence of enzyme called 'chlorophyllase'. The precursor of chlorophyll is chlorophyllide.

Pigments	Chemical Formula	Distribution
Chlorophyll *a*	$C_{55}H_{72}O_5N_4Mg$	All photosynthetic organisms except photosynthetic bacteria.
Chlorophyll *b*	$C_{55}H_{70}O_6N_4Mg$	Chlorophyta, Euglenophyta and in all higher plants.
Chlorophyll *c*	$C_{35}H_{32}O_5N_4Mg$	Brown algae (Phaeophyta), Diatoms and Pyrrophyta.
Chlorophyll *d*	$C_{54}H_{70}O_6N_4Mg$	Red algae (Rhodophyta).
Chlorophyll *e*	Not fully known	Xanthophyta.
Bacteriochlorophyll	$C_{55}H_{74}O_6N_4Mg$	Purple photosynthetic bacteria.
Chlorobiumchlorophyll (Bacterioviridin)		Green sulphur bacteria.

(ii) **Carotenoids :** The carotenoids are unsaturated polyhydrocarbons being composed of eight isoprene (C_5H_8) units. They are made up of two six-membered rings having a hydrocarbon chain in between. 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 absorb light energy and transfer it to Chl. *a* and thus act as **accessory pigments**. They protect the chlorophyll molecules from photo-oxidation by picking up nascent oxygen and converting it into harmless molecular stage. Carotenoids can be classified into two groups namely carotenes and xanthophyll.

(a) **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.

$$\underset{\text{Carotene}}{C_{40}H_{56}} + 2H_2O \xrightarrow{\text{Carotenase}} 2\underset{\text{vitamin A}}{C_{20}H_{29}\ OH}$$

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

Lutein a widely distributed xanthophyll which is responsible for yellow colour in autumn foliage. Fucoxanthin is another important xanthophyll present in Phaeophyceae (Brown algae).

(iii) **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*.

(3) **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 ($h\nu$), 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. Light represents only one part of electromagnetic radiation. Other parts include cosmic rays, X-rays, UV rays, infra-red radiation and radio waves. A visible light has seven separated groups of more or less complete absorption. In a spectrum of sunlight, bands of blending colours are seen *i.e.*, dark red at one end running through red, orange, yellow, green, blue, indigo, violet and ending in darkest violet. Wavelengths in the violet portion of spectrum are about 400 millimicrons ($m\mu$) in length and at other end of spectrum — the red portion — are much longer about $730m\mu$. In other words, visible light lies between

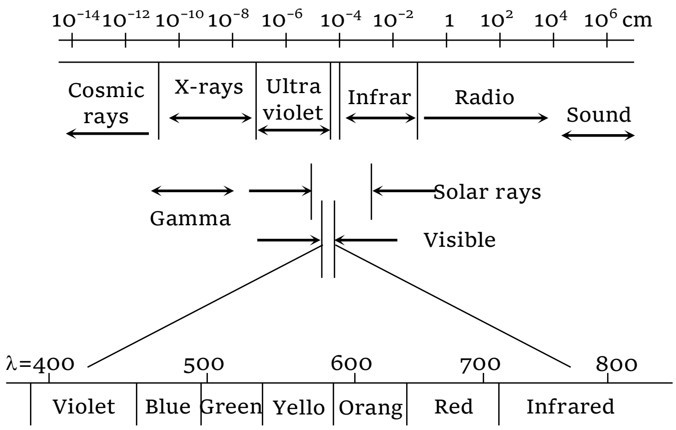


Fig : Electromagnetic spectrum of light

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, art of blue and red wavelengths, blue light carry more energy.

$$\underset{\text{Maximum energy}}{\text{Shortest wavelength}} \longrightarrow \underset{\text{Minimum energy}}{\text{Longest wavelength}}$$

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.

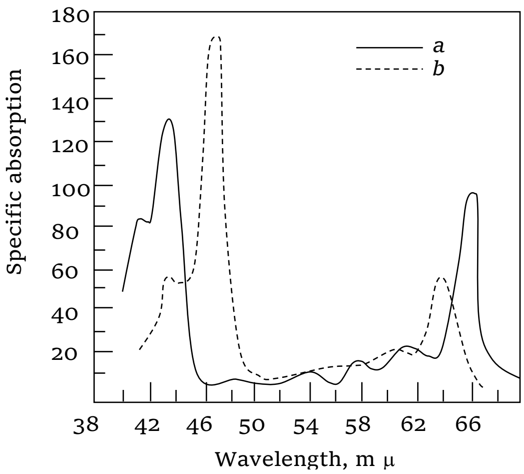


Fig : Absorption spectra of chlorophylls a and b

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**.

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. 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.

5.3 Mechanism of photosynthesis

Before 1930 it was considered by physiologists that one molecule each of CO_2 and H_2O form a molecule of formaldehyde (*HCHO*), of which 6 *mols* are polymerized to one molecule of glucose (a hexose sugar).

$$CO_2 + H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} \underset{\text{(Formaldehyde)}}{HCHO} + O_2$$

$$\underset{\text{(Formaldehyde)}}{6CH_2O (\text{or } 6HCHO)} \xrightarrow{\textit{Polymerisation}} \underset{\text{(Hexose sugar)}}{C_6H_{12}O_6}$$

However formaldehyde is a toxic substance which may kill the plants. Hence, formaldehyde hypothesis could not be accepted.

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 electron donar 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 :

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

The fate of different molecules can be summarised as follows :

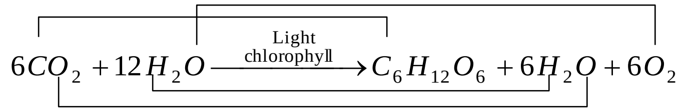


Fig : Fat of different molecules

5.4 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.

Scientist have shown that photosynthesis is completed in two phases.

- **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 $NADPH + H^+$.

- **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 :** Evidences in favour of light and dark phases in photosynthesis are :

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.

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.

Temperature coefficient studies : The temperature coefficient (Q_{10}) is defined as the ratio of the velocity of a reaction at a particular temperature to that at a temperature 10°C lower. For a physical process the value of Q_{10} is slightly greater than one. In photochemical reaction the energy source is light and any increase in temperature is not sufficient to cause an increase in the rate. Thus here also the value of Q_{10} is one. However, in case of chemical reactions the value of Q_{10} is two or more *i.e.*, with the rise of 10°C temperature, the rate of chemical reaction is doubled. If the process of photosynthesis includes a hidden chemical reaction in addition to usual photochemical reaction, its value of Q_{10} should be two or more.

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).

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

(1) **Light phase (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

(i) In photosynthesis oxygen is released from water.

(ii) 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 which 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 :

(i) Transfer of energy (ii) Quantum yield (iii) Emerson effect (iv) Two pigment systems

(v) Z-scheme (vi) Cyclic and non-cyclic photophosphorylation

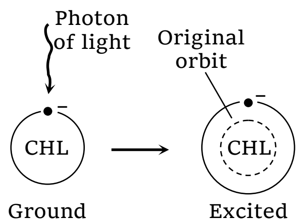


Fig : Photoexcitation of chlorophyll molecule i.e. of its atoms

(i) **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 some time 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**.

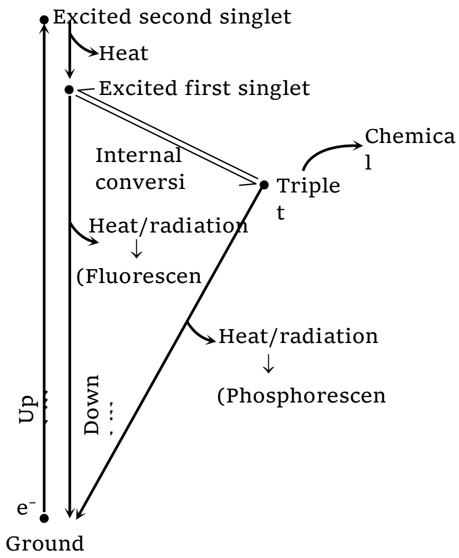


Fig : Movement of electron due to photoexcitation of pigment molecule

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.

(ii) **Quantum yield**

- 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 mols evolved per quantum of light absorbed in photosynthesis."

On the other hand **quantum requirement** is defined as, "Number of quanta of light required for evolution of one mol of O_2 in photosynthesis."

- **Quantum requirement** in photosynthesis = **8**, *i.e.*, **8 quanta** of light are required to evolve one mol. of O_2.
- Hence **quantum yield** = 1 / 8 = 0.125 (*i.e.*, a fraction of 1) as 12%.

(iii) **Emerson effect and Red drop :** 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). 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.

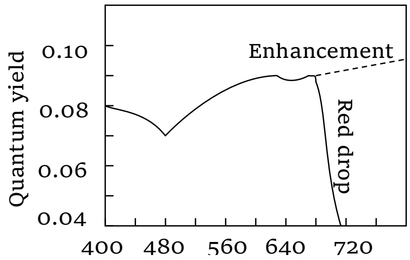


Fig : Red drop

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

(iv) **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. One group of pigments absorbs light of both shorter and longer wavelengths (More than 680*nm*) and another group of pigments absorbs light of only shorter wavelengths (Less than 680*nm*). These two groups of pigments are known as pigment systems or photosystems.

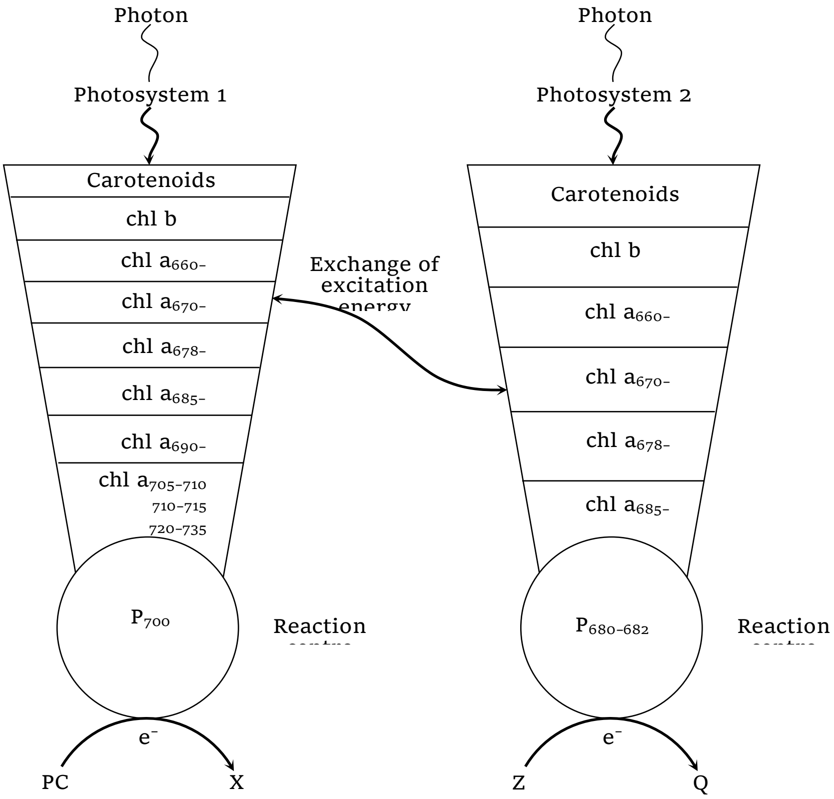


Fig : Distribution of pigments in the two photosystems or pigment systems

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 physiologist 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*.

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 systems I and II are involved in non-cyclic electron transport, while pigment system I is involved only in cyclic electron transport. Photosystem I generates strong reductant NADPH. Photosystem II produces a strong oxidant that forms oxygen from water.

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)	NADPH is formed in this reaction.	NADPH is not formed in this reaction.
(5)	It participate both in cyclic and noncyclic photophosphorylation.	It participate only in noncyclic photophosphorylation.
(6)	It receives electrons from photosystem II.	It receives electrons from photolytic dissociation of water.
(7)	It is not related with photolysis of water.	It is related with photolysis of water.

(v) **Z-Scheme of light reactions :** When sunlight strikes the thylakoid membrane, the energy is absorbed simultaneously by the antenna pigments of both PS I and PS II and passed on to the reaction centers of both photosystems. Electrons of both reaction center pigments are boosted to an outer orbital and each photoexcited electron is transferred to a **primary electron acceptor**. The transfer of electrons out of the photosystems leaves the two reaction center pigments missing an electron and thus, positively charged.

After losing their electrons, the reaction centers of PS I and PS II can be denoted as $P700^+$ and $P680^+$ respectively. Positively charged reaction centers act as attractants for electrons, which sets the stage for the flow of electrons between carriers.

In oxygenic photosynthesis, in which two photosystems act in series, electron flow occurs along three legs-between water and PS II, between PS II and PS I and between PS I and $NADP^+$ an arrangement which is described as the **Z scheme**. The Z scheme as originally proposed by Hill and Bendall, 1960.

(vi) **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**.

$$\mathrm{ADP} + \mathrm{Pi} \xrightarrow[\text{Chlorophyll}]{\text{Light}} \mathrm{ATP}.$$

(Where ADP = Adenosine diphosphate, Pi = Inorganic phosphate and ATP = Adenosine triphosphate).

When the light quantum is absorbed by various types of pigments (Like chlorophylls, phycobilins, carotenoids etc.), it is transferred to reaction centre *i.e.* P_{700} in PS I and P_{680} in PS II. Electrons excite from reaction centres due to funneling of energy. P_{700} gets photo excited and comes under first excited singlet state. As a result electron is lost, which is accepted by an electron, acceptor in the way. After absorbing light, excited electron liberated from reaction centre interacts with water.

$$4H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} 4H^+ + 4OH^-$$

$$4OH^- + 4e^- \rightarrow 4OH$$

$$4OH^- \rightarrow 2H_2O + O_2$$

$$4H^+ + 2A + 4e^- \rightarrow 2AH_2$$

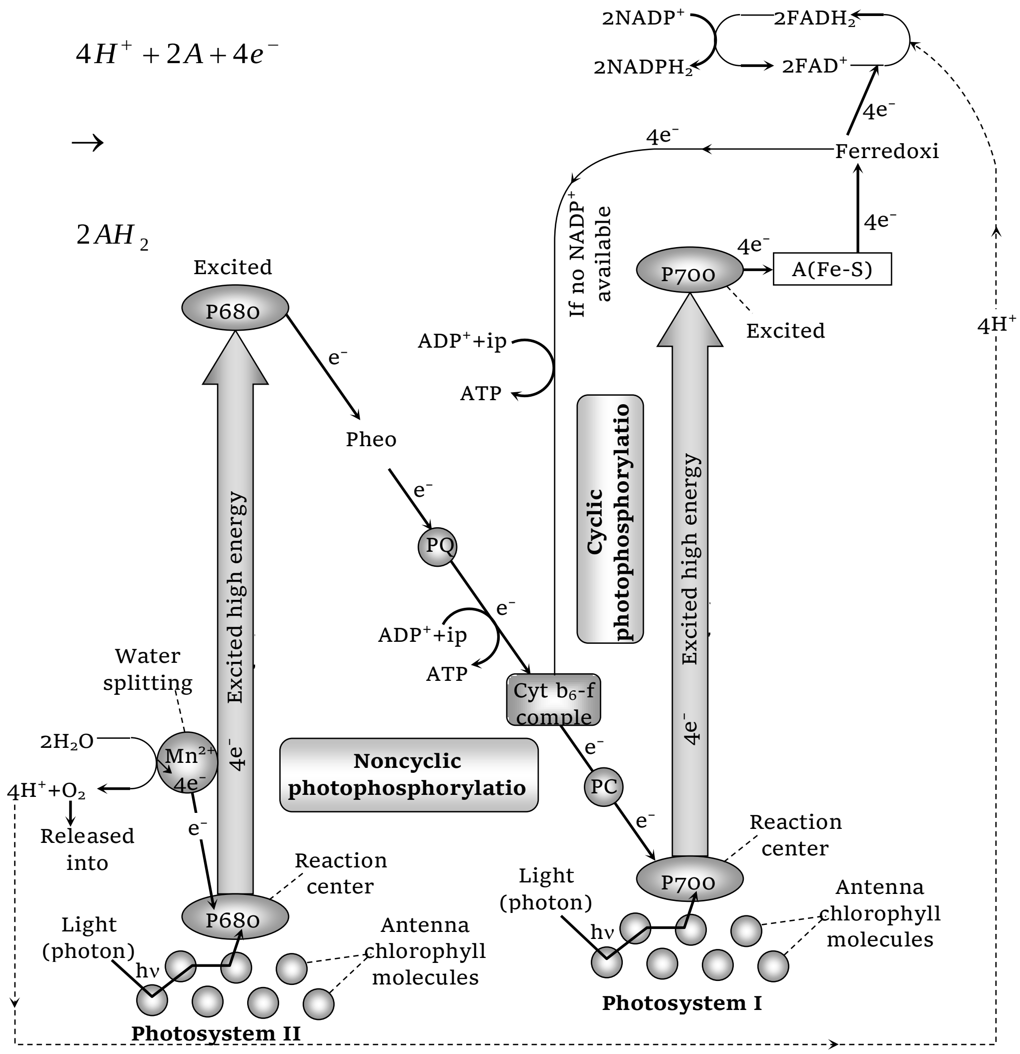


Fig : The Z-scheme of photosynthesis simplified diagram of the electron flow from H_2O to $NADP^+$

Another important aspect of light reactions is the formation of ATP and $NADPH_2$ (**Assimilatory power**). H^+ from water and electron from chlorophyll are made available to NADP to form $NADPH_2$. The electrons are accepted by NADP after passing through electron carriers. The carriers in the way undergo oxidation and reduction and are arranged in accordance with their **redox potential** value.

Photophosphorylation is of two types

(a) **Cyclic photophosphorylation :** It involves only PS I. Flow of electron is cyclic. When NADP is not available then this process will occurs. 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}.

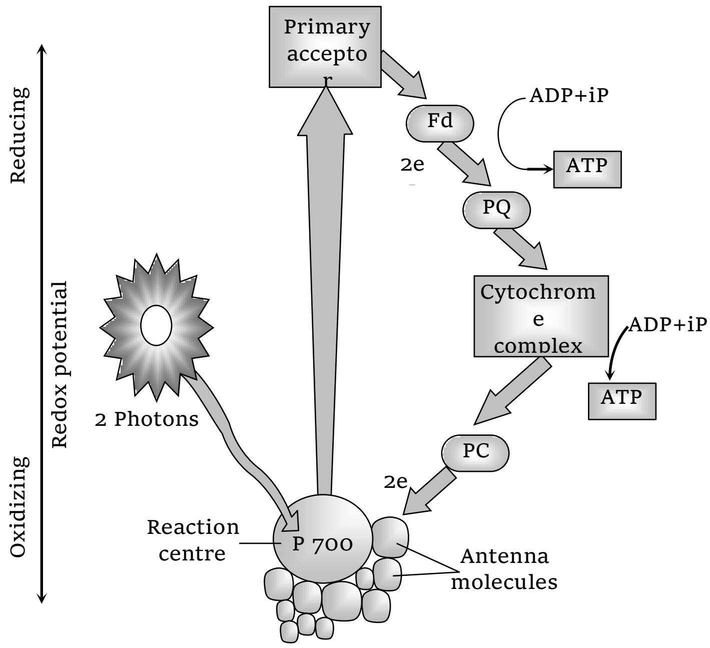


Fig : Cyclic photophosphorylation

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.

(b) **Non cyclic photophosphorylation :** It involves both PS-I and PS-II. Flow of electron 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 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.

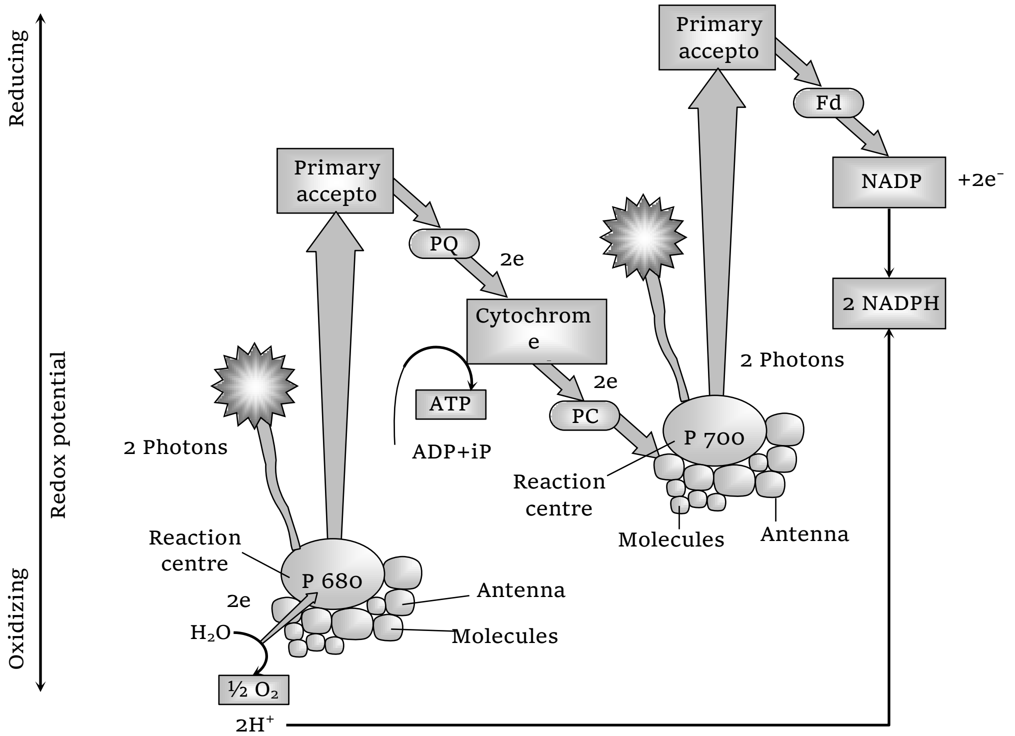


Fig : Non cyclic photophosphorylation

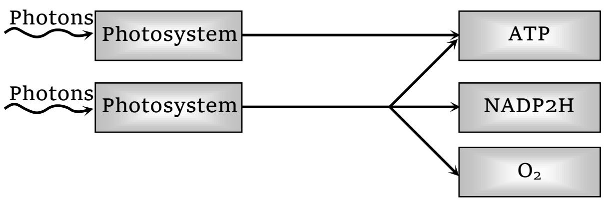


Fig : Final products of light reactions

Comparison of cyclic and noncyclic photophosphorylation

S.No.	Cyclic photophosphorylation	Noncyclic photophosphorylation
(1)	No oxygen is given off (Anoxygenic).	Oxygen is given off (Oxygenic).
(2)	No water is consumed.	Water is used up.
(3)	Only one light-trapping system (Photosystem I) is involved.	Two light-trapping systems (Photosystem I and II) are involved.
(4)	No NADPH synthesized.	NADPH synthesized
(5)	Last electron acceptor is P_{700}	Last electron acceptor is NADP.
(6)	The system is found dominantly in bacteria.	The system is dominant in green plants.
(7)	The process is not inhibited by DCMU.	The process is stopped by use of DCMU

(c) **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 Pi (Inorganic phosphate) in presence of FMN or vit. K and oxygen. The process is thus very simple and requires no net chemical change but 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.

$$\text{FMN} + \underset{\text{ADP+Pi} \;\rightarrow\; \text{ATP}}{\xrightleftharpoons{\text{Illuminated chloroplast}}} \text{FMNH}_2 + \tfrac{1}{2}\,\text{O}_2$$

(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 :

(i) Calvin cycle (C_3) (ii) Hatch and Slack cycle (C_4) (iii) Crassulacean acid metabolism (CAM plants)

(i) **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.

- **Carboxylation :** CO_2 reduction starts with a 5-carbon sugar, ribulose-5-phosphate. 6 molecules of this sugar react with 6 molecules of ATP (Produced in light reactions) forming 6 molecules of ribulose-1, 5-biphosphate (RuBP) and 6 molecules of ADP. (equation i).

$$\underset{(6\,mols)}{\text{Ribulose -5 – phosphate}} + 6\text{ATP} \xrightarrow{\text{Phosphopentokinase}} \underset{(6\,mols)}{\text{Ribulose -1, 5 – biphosphate}} + 6\text{ADP} \quad \text{….. (i)}$$

The reaction is catalysed by the enzyme ribulose biphosphate carboxylase (RUBISCO). 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 (a 3 carbon compound) (equation ii).

$$\underset{(6\ \text{mols})}{\text{Ribulose-1,5-biphosphate}} + 6CO_2 + 6H_2O \xrightarrow[\text{Ribulose-1,5-biphosphate carboxylase}]{\text{Carboxydismutase}} \underset{(12\ mols)}{\text{3-phosphoglyceric acid}} \quad \ldots\ \text{(ii)}$$

- **Glycolytic reversal :** Carboxylation is followed by reactions that involve reversal of glycolysis part of respiration.

12 mols of 3-phosphoglyceric acid react with 12 mols of ATP (Produced in light reactions) giving rise to 12 mols each of 1, 3-diphosphoglyceric acid + ADP (equation iii).

$$\underset{(12\ mols)}{\text{3-phosphoglyceric acid}} + 12\,\text{ATP} \xrightarrow{\text{Phosphoglyceric kinase}} \underset{(12\ mols)}{\text{1,3-diphosphoglyceric acid}} + 12\,\text{ADP} \quad \ldots\ \text{(iii)}$$

12 mols of NADP.2H formed in light reactions are used to reduce 12 mols of 1,3-diposphoglyceric acid leading to the formation of 12 mols of 3-phosphoglyceraldehyde, 12 moles of NADP and 12 moles of phosphoric acid (equation iv).

$$\underset{(12\ mols)}{\text{1,3-diphosphoglyceric acid}} + 12\,\text{NADP.2H} \xrightarrow{\text{Triose phosphate dehydrogenase}}$$

$$\underset{(12\ mols)}{\text{3-phosphoglyceraldehyde}} + 12\,\text{NADP}^+ + 12H_3PO_4 \quad \ldots\ \text{(iv)}$$

In this way by the reduction of CO_2, 12 molecules of 3-phosphoglyceraldehyde are formed. Out of these 12 molecules, 2 molecules go to synthesize sugar, starch and other carbohydrates and remaining 10 molecules are recycled to regenerate 6 molecules of ribulose 5 phosphate.

Out of two mols of 3-phosphoglyceraldehyde one mol is converted to its isomer 3-dihydroxyacetone phosphate (equation v).

$$\underset{(1\ mol)}{\text{3-phosphoglyceraldehyde}} \xrightarrow[\text{Isomerase}]{\text{Phosphotriose}} \underset{(1\ mol)}{\text{3-dihydroxy acetone phosphate}} \quad \ldots\ \text{(v)}$$

One mol of 3-dihydroxyacetone phosphate react with 1 mol of 3-phosphoglyceraldehyde to form one molecule of fructose-1,6-biphosphate (equation vi).

$$\underset{(1\ mol)}{\text{Phosphoglyceraldehyde}} + \underset{(1\ mol)}{\text{Dihydroxyacetone phosphate}} \xrightarrow{\text{Aldolase}} \underset{(1\ mol)}{\text{Fructose-1,6-biphosphate}} \quad \ldots\ \text{(vi)}$$

One mol of fructose-6-phosphate and one mol of phosphoric acid is released from one mol of fructose-1,6-biphosphate with the help of the enzyme phosphatase with utilizations of one mol of H_2O (equation vii).

$$\underset{(1\ mol)}{\text{Fructose-1,6-biphosphate}} \xrightarrow[H_2O]{\text{Phosphatase}} \underset{(1\ mol)}{\text{Fructose-6-phosphate}} + H_3PO_4 \quad \ldots\ \text{(vii)}$$

Fructose-6-phosphate can be converted to other sugars (viz., glucose, sucrose, starch, etc.). In this way, the atmospheric CO_2 is used in the synthesis of carbohydrates.

- **Regeneration of RuBP :** Both triose phosphates, *i.e.*, 3-phosphoglyceraldehyde and dihydroxy acetone phosphate, actively participate in the regeneration of CO_2-acceptor ribulose-1,5-diphosphate.

The sequence of reactions are as follows :

(i) $\underset{\substack{(PGAL)\\ [4\ mols]}}{3-\text{phosphoglyceraldehyde}} \xrightarrow[\text{Isomerase}]{\text{Triose phosphate}} \underset{\substack{(DHAP)\\ [4\ mols]}}{\text{Dihydroxy acetone phosphate}}$

(ii) $\underset{[2\ mols]}{\text{Dihydroxyacetone phosphate}} + \underset{[2\ mols]}{3-\text{phosphoglyceraldehyde}} \xrightarrow{\text{Aldolase}} \underset{[2\ mols]}{\text{Fructose - 1,6 - diphosphate}}$

(iii) $\underset{[2\ mols]}{\text{Fructose -1,6 - diphosphate}} + 2H_2O \xrightarrow{Phosphatase} \underset{[2\ mols]}{\text{Fructose - 6 - phosphate}} + 2H_3PO_4$

(iv) $\underset{[2\ mols]}{\text{Fructose - 6 - phosphate}} + \underset{[2\ mols]}{3-\text{phosphoglyceraldehyde}} \xrightarrow{\text{Transketolase}}$

$\underset{[2\ mols]}{\text{Xylulose - 5 - phosphate}} + \underset{[2\ mols]}{\text{Erythrose - 4 - phosphate}}$

(v) $\underset{\substack{[2\ mols]\\ (\text{Produced in reaction (iv)})}}{\text{Erythrose - 4 - phosphate}} + \underset{\substack{[2\ mols]\\ \text{of the 4 mols produced in reaction (i)}}}{\text{Dihydroxyacetone phosphate}} \xrightarrow{\text{Transaldolase}} \underset{[2\ mols]}{\text{Sedoheptulose-1,7 - diphosphate}}$

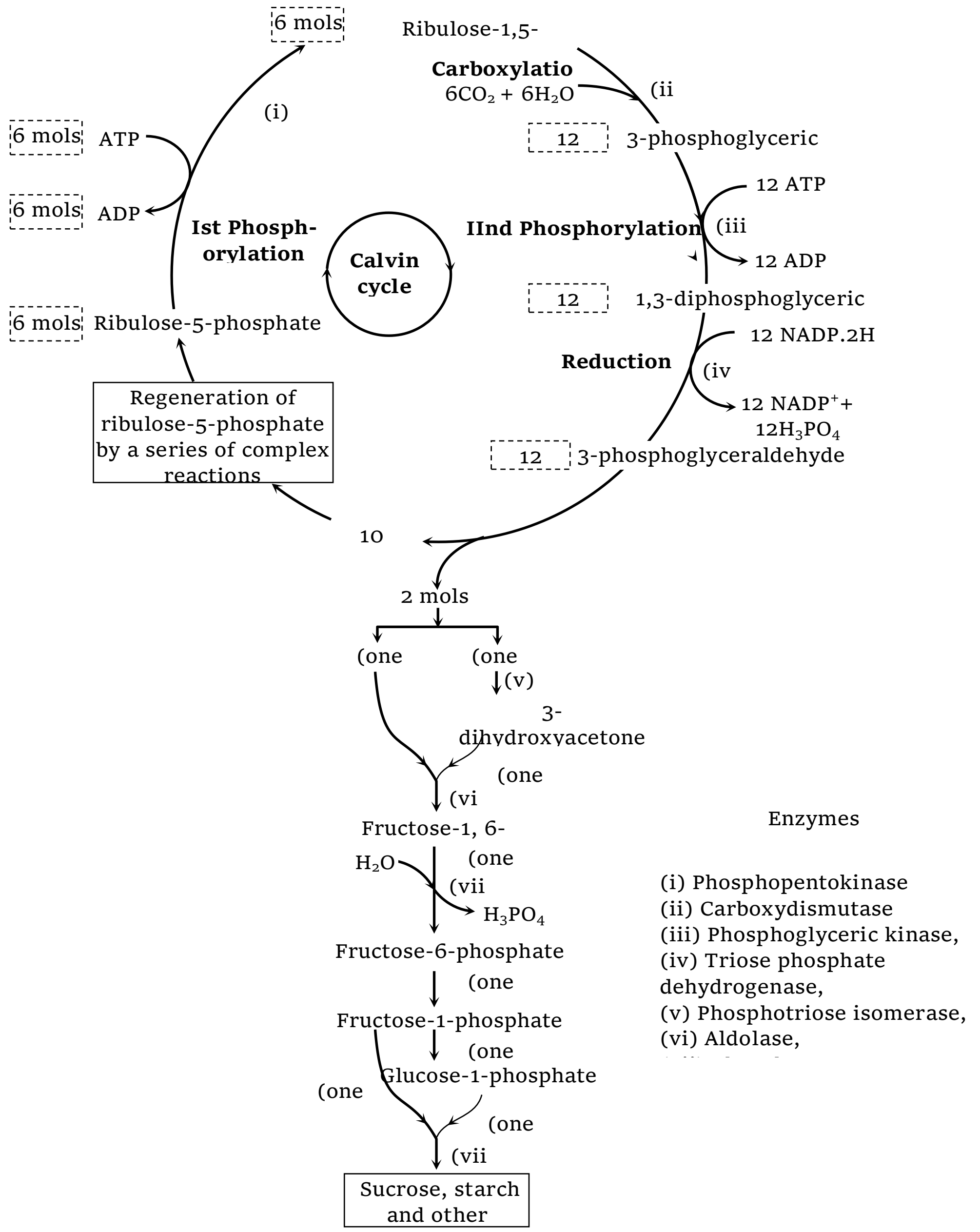


Fig : Simplified diagram of Calvin cycle

(vi) $\underset{[2\text{ mols}]}{\text{Sedoheptulose-1,7 – diphosphate}} \xrightarrow{\text{Phosphatase}} \underset{[2\text{ mols}]}{\text{Sedoheptulose- 7 – phosphate}} + 2H_3PO_4$

(vii) $\underset{[2\text{ mols}]}{\text{Sedoheptulose- 7 – phosphate}} + \underset{[2\text{ mols}]}{\text{3 - phospho glyceraldehyde}} \xrightarrow{\text{Transketolase}}$

$$\underset{[2\text{ mols}]}{\text{Ribose- 5 – phosphate}} + \underset{[2\text{ mols}]}{\text{Xylulose- 5 – phosphate}}$$

(viii) $\underset{\substack{[2\text{ mols}] \\ \text{(Produced in reaction (vii))}}}{\text{Ribose- 5 – phosphate}} \xrightarrow{\text{Phosphopentose isomerase}} \underset{[2\text{ mols}]}{\text{Ribulose - 5 – phosphate}}$

(ix) $\text{Xylulose-5-phosphate} \xrightarrow{\text{Phosphopentose epimerase}} \underset{[4\text{ mols}]}{\text{Ribulose - 5 – phosphate}}$

2 + 4 = 6 molecules of Ribulose 5 phosphate are formed during the changes from equation (viii) and (ix) these molecule changed in Ribulose 1, 5 diphosphate (RuDP) by the consumption of 6 ATP. These RuDP again ready for reduction of new molecules of CO_2. Hence in this way regeneration of RuDP is going on. They are used in next calvin cycle. In the overall reactions 18 ATP molecules and 12 $NADPH_2$ molecules consumed and one molecule of glucose (Hexose) is obtained (1 $NADPH_2$ = 3ATP $\therefore$ Total ATP consumed = 54 ATP). The whole photosynthesis can be summarized in terms of equation which is as follows :

Light reaction : $12H_2O + 12\,NADP + 18\,ADP + 18\,Pi \rightarrow NADPH - H^+ + 18\,ATP + 6O_2$

Dark reaction : $6CO_2 + 12\,NADPH - H^+ + 18\,ATP \rightarrow C_6H_{12}O_6 + 6H_2O + 12\,NADP + 18\,ADP + 18\,Pi$

Final equation : $6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$

(ii) **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 dicarboxylic group. Hence it is called dicarboxylic acid cycle or DCA-cycle. C_4 plants are true xerophytic plants.

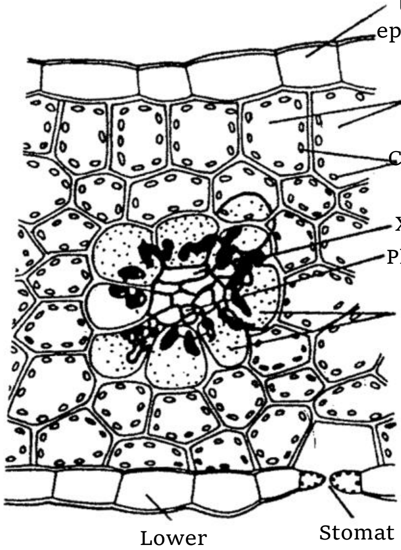


Fig : Cross section of leaf showing “krantz” type of

The plants that perform C_4 cycle are found in tropical (Dry and hot regions) and sub-tropical regions. There are more than 900 known species in which C_4 cycle occurs. Among them, more than 300 species belong to dicots and the rest belong to monocots. The important among them 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. The mesophyll cells perform C_4 cycle and the cells of bundle sheath perform C_3 cycle.

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. Mesophyll cells have PEP carboxylase and pyruvate orthophosphate dikinase enzyme while the bundle sheath cells have decarboxylase and complete enzymes of Calvin cycle. In C_4 plants, there are 2 carboxylation reactions, first in mesophyll chloroplast and second in bundle sheath chloroplast.

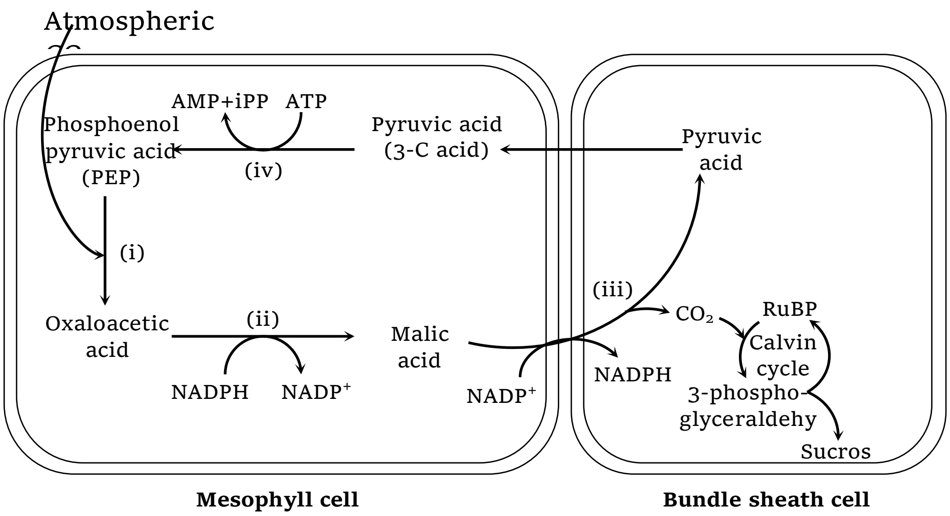


Fig : Hatch-slack pathway (cycle)
Enzymes : (i) Phosphoenol pyruvate carboxylase, (ii) Malate dehydrogenase,

C_4 plants are better photosynthesizers. There is no photorespiration in these plants. In C_4 plants, for formation of one mole of hexose (glucose) 30 ATP and 12 $NADPH_2$ are required. There is difference in different C_4 plants in mechenism of C_4 mode of photosynthesis. The main difference is in the way the 4C dicarboxylic acid is decarboxylated in the bundle sheath cells. The three categories of C_4 pathways in C_4 plants are recognised such as :

(a) Some C_4 plants *e.g.*, *Zea mays*, *Saccharum officinarum*, *Sorghum* utilise $NADP^+$ specific malic enzyme for decarboxylation. This mechanism of C_4 pathway in these C_4 plants is said to be of **$NADP^+$ –Me Type**.

(b) Some C_4 plants *e.g.*, *Atriplex*, *Portulaca*, *Amaranthus* utilise NAD^+ specific malic enzyme for decarboxylation. This mechanism of C_4 pathways in these C_4 plants is said to be of **NAD^+ –Me Type**.

(c) Some C_4 plants *e.g., Panicum, Chloris* utilise PEP-carboxykinase enzyme. The mechanism of C_4 pathway in these plants is called as **PCK-me-Type**.

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

(a) PEP carboxylase has great affinity for CO_2.

(b) 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 require 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).

Differences between C_3 and C_4 plants

S.No.	Characters	C_3 plants	C_4 plants
(1)	CO_2 acceptor	The CO_2 acceptor is Ribulose 1,5 diphosphate.	The CO_2 acceptor is phosphoenol-pyruvate.
(2)	First stable product	The first stable product is phosphoglyceric acid.	Oxaloacetate is the first stable product.
(3)	Type of chloroplast	All cells participating in photosynthesis have one type of chloroplast.	The chloroplast of parenchymatous bundle sheath is different from that of mesophyll cells. Leaves have 'Kranz' type of anatomy. The bundle sheath chloroplasts lack grana. Mesophyll cells have normal chloroplasts.
(4)	Cycles	Only reductive pentose phosphate cycle is found.	Both C_4-dicarboxylic acid and reductive pentose phosphate cycles are found.
(5)	Optimum temperature	The optimum temperature for the process is 10-25°C.	In C_4 plants, it is 30-45°C.
(6)	Oxygen inhibition	Oxygen present in air (=21% O_2) markedly inhibit the photosynthetic process as compared to an external atmosphere containing no oxygen.	The process of photosynthesis is not inhibited in air as compared to an external atmosphere containing no oxygen.

(7)	PS I and PS II	In each chloroplast, photosystems I and II are present. Thus, the Calvin cycle occurs.	In the chloroplasts of bundle sheath cells, the photosystem II is absent. Therefore, these are dependent to mesophyll chloroplast for the supply of NADPH + H^+
(8)	Enzymes	The Calvin cycle enzymes are present in mesophyll chloroplast.	Calvin cycle enzymes are absent in mesophyll chloroplasts. The cycle occurs only in the chloroplasts of sheath cells.
(9)	Compensation point	The CO_2 compensation point is 50-150ppm.	CO_2 compensation point is 0-10ppm.
(10)	Photorespiration	Photorespiration is present and easily detectable.	Photorespiration is present only to a slight degree and difficult to detect.
(11)	Net rate	Net rate of photosynthesis in full sunlight (10,000-12,000 ft.c) is 15-35mg. of CO_2 per dm^2 of leaf area per h.	It is 40-80mg. of CO_2 per dm^2 of leaf area per h. That is photosynthetic rate is quite high. The plants are efficient.
(12)	Saturation intensity	The saturation intensity reached in the range of 100-4000 ft.c.	It is difficult to reach saturation even in full sunlight.

(iii) **Crassulacean acid metabolism plants (CAM plants) :** This dark CO_2 fixation pathway proposed by **Ting** (1971). It operates in succulent or fleshy plants *e.g. Cactus*, *Sedum*, *Kalanchose*, *Opuntia*, *Agave*, orchid, pine apple 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 (Scotactive 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. The metabolic pathways are –

- **Acidification :** In dark, stored carbohydrates are converted to phosphoenol pyruvic acid (PEP) by the process of glycolysis. The opening of stomata in CAM plants in dark causes entry of CO_2 in leaf. So, phosphoenol pyruvic acid in presence of PEP carboxylase is converted to oxaloacetic acid (OAA). OAA is then reduced to malic acid in presence of enzyme malic dehydrogenase with the help of $NADH_2$. This malic acid (Produced by acidification) is stored in vacuole.

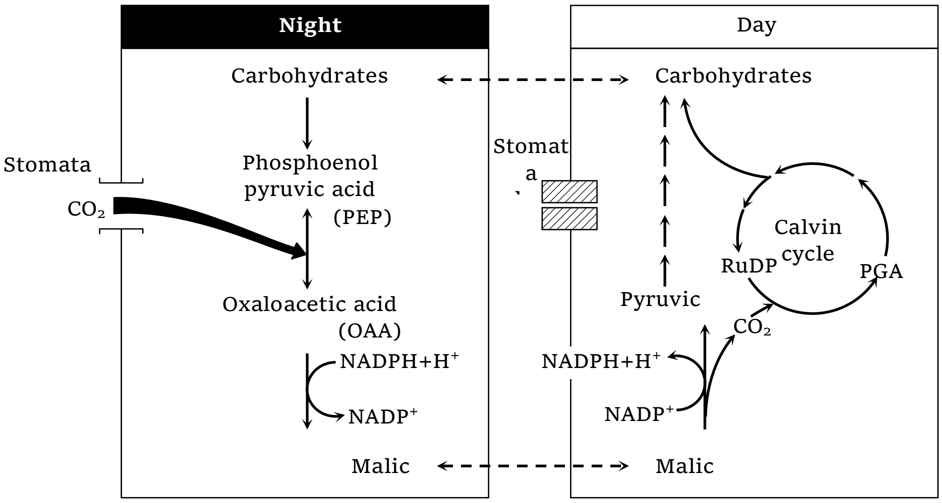


Fig : CAM

- **Deacidification :** In light the malic acid is decarboxylated to produce pyruvic acid and evolve CO_2. This process is called <u>deacidification</u>.

The malate may be decarboxylated in two ways –

(a) In some CAM plants the malate is directly decarboxylated in the presence of $NADP^+$ malic enzyme into CO_2 and pyruvate (ME-CAM plants).

(b) In other CAM plants, the malate is first oxidised to oxaloacetic acid by enzyme malate dehydrogenase which is then converted into CO_2 and phosphoenol pyruvate with the utilization of ATP by enzyme PEP carboxykinase (PEPCK-CAM plants).

The CO_2 produced by any above process is then consumed in normal photosynthetic process to produce carbohydrate.

Characteristics of CAM pathway

(1) CO_2 assimilation and malic acid assimilation take place during the night.

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

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

(4) 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.

5.5 PHOTORESPIRATION (PHOTOSYNTHETIC CARBON OXIDATION 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 <u>biosynthesis of glycolate</u> in chloroplasts and subsequent metabolism of glycolate acid in the same leaf cell. Biochemical mechanism for photorespiration is also called glycolate metabolism. <u>Loss of energy occurs during this process. The process of photorespiration involves the involvement of chloroplasts, peroxisomes and mitochondria</u>. RuBP carboxylase also catalyses another reaction which interferes with the successful functioning of Calvin cycle.

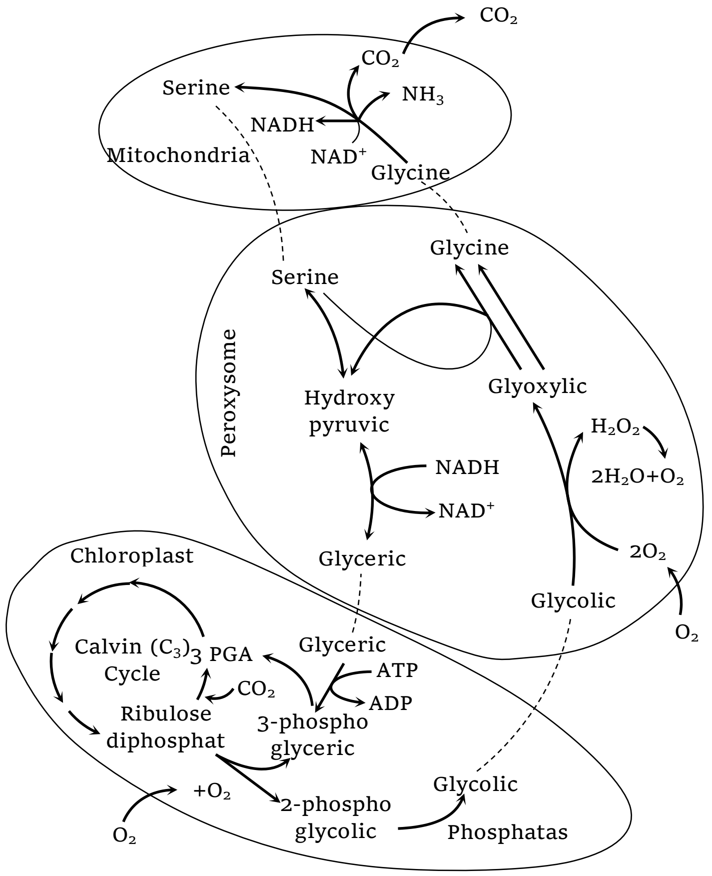


Fig : The biochemical pathway of

Biochemical mechanism

(1) Ribulose bisphosphate carboxylase (RUBISCO), the main enzyme of Calvin cycle that fixes CO_2, acts as ribulose bisphosphate oxygenase under low atmospheric concentration of CO_2 (*i.e.*, below 1%) and increased concentration of O_2. In presence of high concentration of O_2 the enzyme RuBP oxygenase splits a molecule of Ribulose-1, 5-bisphosphate into one molecule each of 3-phosphoglyceric acid and 2-phosphoglycolic acid.

$$\text{Ribulose-1, 5- bisphosphate} \xrightarrow{O_2} \text{2 Phosphoglycolic acid} + \text{3 Phosphoglyceric acid}$$

(2) The 2-phosphoglycolic acid loses its phosphate group in presence of enzyme phosphatase and converted into glycolic acid –

$$\text{2 Phosphoglycolic acid} + H_2O \longrightarrow \text{Glycolic acid} + \text{Phosphoric acid.}$$

(3) The glycolic acid, synthesized in chloroplast as an early product of photosynthesis, is then transported to the peroxisome. The glycolic acid reacts with O_2 and oxidizes to glyoxylic acid and hydrogen peroxide with the help of enzyme glycolic acid oxidase.

$$\text{Glycolic acid} + O_2 \longrightarrow \text{Glyoxylic acid} + H_2O_2$$

The hydrogen peroxide is destroyed by enzyme catalase as follows :

$$2H_2O_2 \longrightarrow 2H_2O + O_2$$

(4) The glyoxylic acid is then converted to an amino acid-glycine by transamination reaction catalyzed by enzyme glutamate-glyoxylate transaminase.

Glyoxylic acid + Glutamic acid $\longrightarrow$ Glycine + α-keto glutaric acid

(5) The glycine is transported out of peroxisomes into mitochondria, where two molecules of glycine interact to form one molecule each of serine, CO_2 and NH_3 –

2 Glycine + H_2O + NAD^+ $\longrightarrow$ Serine + CO_2 + NH_3 + $NADH$

The CO_2 is then released in photorespiration from mitochondria. The NH_3 released during glycine decarboxylation is transported to cytoplasm or chloroplast, where it is incorporated into synthesis of glutamic acid.

(6) The amino acid serine returns to peroxisome where it is deaminated and reduced to hydroxypyruvic acid and finally to glyceric acid –

Serine + Glyoxylic acid $\longrightarrow$ Hydroxypyruvic acid + Glycine Hydroxypyruvic acid $\longrightarrow$ Glyceric acid

(7) The glyceric acid finally enters the chloroplast where it is phosphorylated to 3-phosphoglyceric acid, which enters into C_3 cycle –

Glyceric acid + ATP $\longrightarrow$ 3-Phosphoglyceric acid + ADP + Phosphate.

Importance of photorespiration : The process of photorespiration interferes with the successful functioning of Calvin cycle. 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.

It is absent in plants which have very low CO_2 compensation point such as maize, sugarcane (C_4 plants). Photorespiration generally occurs in **temperate** plants. Few photorespiring plants are : Rice, bean, wheat, barley, rice 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.

Differences between photorespiration, photosynthesis and true respiration

S.No.	Photorespiration	Photosynthesis	True Respiration
(1)	Occurs in green plants in light.	Occurs in green plants in light.	Occurs in all living organisms in light and dark.
(2)	The primary substrate is glycolate formed from RuBP.	Substrate is CO_2 and H_2O.	Substrates are carbohydrates, fat and proteins.
(3)	Occurs in most of the C_3 plants.	Occurs in all green plants.	Occurs in all living organisms.
(4)	Intracellularly, the process occurs in peroxisomes in association with chloroplasts and mitochondria.	Occurs in chloroplasts.	Occurs in cytosol and mitochondria.
(5)	The process increases with increasing concentration of O_2 and decreasing concentration of CO_2.	The process is inhibited with increasing concentration of O_2.	The process saturates at 2-3% O_2 in the atmosphere and beyond this conc, virtually no increase occurs.
(6)	Hydrogen peroxide is formed during this process.	H_2O_2 is not formed.	H_2O_2 is not formed.
(7)	Phosphorylation does not occur.	Photophosphorylation occurs.	Oxidative phosphorylation occurs.

***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. Rate of photosynthesis is higher than that of respiration during day time and ratio of O_2 produced to that consumed is 10 : 1.

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.

During compensation point there is no evolution of any gas.

5.6 Adenosine triphosphate (ATP)

A molecule of Adenosine is formed by reaction between a molecule of adenine (A nitrogenous base) and sugar D-ribose (A pentose sugar). Adenosine is a nucleoside. Adenosine monophosphate (AMP = Adenylic acid) is formed by condensation of a phosphate group at CH_2OH site of 5th carbon atom of deoxyribose sugar.

With the formation of this bond (represented by –) between sugar and phosphate energy of 1500-1800 cal./mol is stored. This is low energy bond. When next group of phosphate is attached to AMP, Adenosine diphosphate (ADP) is formed. In this bond 7300 cal./mol of energy is stored and this bond is represented by wavy lines (~). This is high energy bond. In the same way when third phosphate group is attached to ADP, ATP is formed. This third bond is also represented by wavy line (~) and the energy stored is equal to the second bond.

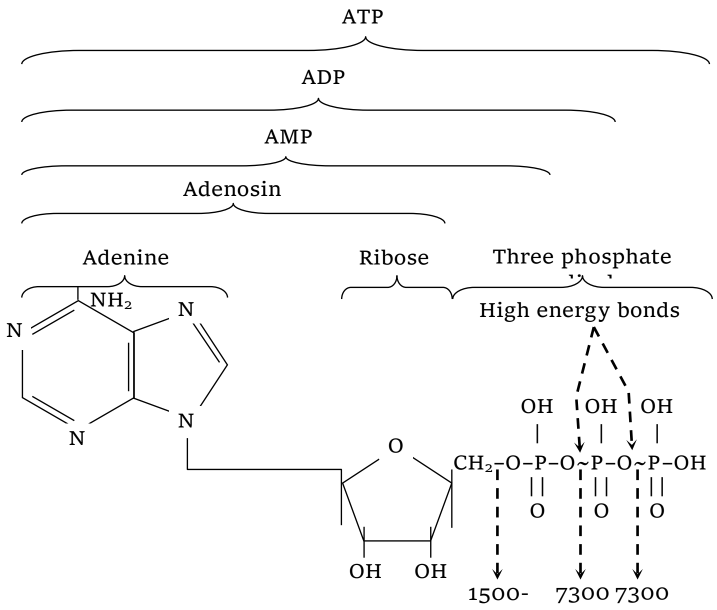


Fig : Molecular structure of Adenosine Triphosphate

In photochemical reactions of photosynthesis 18 ATP molecules are synthesized. Out of these 18 molecules of ATP, 6 react with ribulose monophosphate to form ribulose-1,5-biphosphate and the remaining 12 molecules react with 12 mols of 3-phosphoglyceric acid to form 12 mols of 1,3-diphosphoglyceric acid. ATP synthesized in cyclic and noncyclic photophosphorylation is utilized in dark reaction of photosynthesis.

Functions of ATP : In living cells energy yielding and energy consuming reactions take place continuously. By release of energy from one substance (*e.g.*, glucose) another substance, *e.g.*, protein is synthesized. By release of energy from proteins other activities of plants can be carried out. There is a mechanism of temporary storage of energy in the cells. This is ATP. This chemical is extremely important for all living cells. Energy released as a result of oxidation of carbohydrates, proteins and fats is utilized in the synthesis of ATP (from ADP and inorganic phosphate). This method of synthesis of ATP in respiration is called **oxidative phosphorylation** which is essential for various other synthetic activities, *e.g.*, synthesis of carbohydrates, fats, proteins and osmosis, active absorption, translocation of foods, streaming of protoplasm, growth, etc. In this way by taking out energy from one compound and transferring it to another, ATP, functions as an **intermediary compound of energy transfer**. This is why ATP is called as **monetary system of energy exchange** in living organisms.

5.7 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 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.

- Bacterial chlorophyll
- Bacterio viridin

The photosynthetic bacteria fall under three categories :

(1) **Green sulphur bacteria :** They are autotrophic. The hydrogen donor is H_2S and the pigment involved in the process is **chlorobium chlorophyll** (Bacterioviridin) *e.g. Chlorobium*.

$$6CO_2 + 12H_2S \xrightarrow[\text{Chlorobium chlorophyll}]{} C_6H_{12}O_6 + 6H_2O + 12S\ .$$

(2) **Purple sulphur bacteria :** They are also autotrophic. The hydrogen donor is thiosulphate and the pigment involved in photosynthesis is **bacteriochlorophyll a**. *e.g., Chromatium*.

$$6CO_2 + 15H_2O + 3Na_2S_2O_3 \xrightarrow[\text{Bacteriochlorophyll a}]{} C_6H_{12}O_6 + 6H_2O + 6NaHSO_4\ .$$

(3) **Purple non-sulphur bacteria :** They are heterotrophic utilizing succinate or malate or alcohol. *e.g., Rhodospirillum, Rhodopseudomonas*.

$$6CO_2 + 12CH_3CHOHCH_3 \longrightarrow C_6H_{12}O_6 + 12CH_3COCH_3 + 6H_2O$$

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.

5.8 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 :** These bacteria oxidises ammonia to nitrites and release chemical energy. *e.g. Nitrosomonas, Nitrococcus* etc.

$$NH_4^+ + 2O_2 \longrightarrow NO_2 + 2H_2O + \text{energy}$$

(2) **Sulphur bacteria :** Convert H_2S to sulphur. *e.g, Beggiatoa, Thiothrix* and *Thiobacillus*.

$$H_2S + O_2 \longrightarrow 2H_2O + 2S + \text{energy}$$

(3) **Iron bacteria :** Oxidises ferrous to ferric *e.g. Ferrobacillus, Leptothrix* and *Cladothrix*.

$$\underset{\text{(Ferrous)}}{Fe^{2+}} \longrightarrow \underset{\text{(Ferric)}}{Fe^{3+}} + \text{energy}$$

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

$$H_2 \xrightarrow{[O]} (H_2O) + \text{energy}$$

(5) **Carbon bacteria :** Convert carbon monoxide to carbon dioxide. *e.g., Carboxydomonas, Bacillus oligocarbophilus*.

$$CO \xrightarrow{[O]} CO_2 + \text{energy}$$

5.9 Factors affecting photosynthesis

- **Blackmann's law of limiting factors**

F.F. Blackmann (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'. Blackmann's law of limiting factor is modification of Leibig'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 no photosynthesis occurs, an optimum value showing highest rate and a maximum value, above which photosynthesis fails to take place. The law can be explained best by the following illustration :

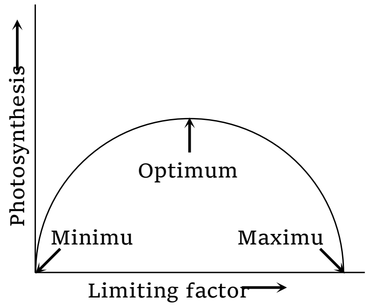


Fig : The concept of

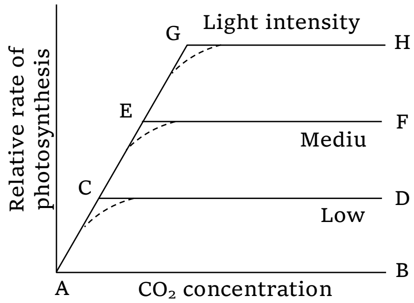


Fig : Blackman's law of limiting

Light intensity provided to a leaf is just sufficient to permit it to utilize 5 *mg* of CO_2. At 'A' no photosynthesis occurs due to non-availability of CO_2. If concentration is increased from 0 to 1 *mg,* rate of photosynthesis will increase from 'A' to 'C'. Now even if the CO_2 concentration is further increased to 5 *mg* rate becomes constant. Further increase from 'C' to 'E' is possible only when light intensity is increased, which is at this time working as limiting factor. Because the factor which is quantitatively smaller may not be limiting one, while a factor which is relatively less than the amount actually required will act as limiting factor. That is why many modifications in name have been suggested *e.g.* **'Law of relatively limiting factor'** or **'Law of most significant factor'**.

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

(1) **External factors :** These include light, temperature, CO_2, water and oxygen.

(i) **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.

(a) **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**.

(b) **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.

(c) **Duration of light :** Longer duration of light period favours photosynthesis. Generally, if the plants get 10 to $12hrs$ 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.

(ii) **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 conifers at high altitudes at $35°C$. Some algae in hot springs can undergo photosynthesis even at $75°C$.

(iii) **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 inhibit photosynthesis.

(iv) **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.

(v) **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.

(vi) **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.

(vii) **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.

(2) **Internal factors**

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

These factors effect 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.

(ii) **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 leaved variety. **Emerson** (1929) also found a direct relationship between chlorophyll contents and photosynthetic rate in *Chlorella*.

(iii) **Accumulation of products :** The food is largely prepared in the mesophyll cells of the leaf from where it is translocated to storage regions. If the rate of translocation becomes slower than the rate of manufacture, the former declines due to accumulation of end products.

(iv) **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.

5.10 SIGNIFICANCE OF PHOTOSYNTHESIS

(1) **Synthesis of food :** Body of all living organism and their survival is dependent upon foods (Carbohydrates, fats and proteins). They need energy for different life activities which is derived from foods. Green plants are unique in the character that they are able to synthesize foods for all living beings.

(2) **Purification of atmosphere :** By oxidation of carbohydrates, fats and proteins CO_2 is released along with energy. Coal, petrol and many other type of oils release CO_2 when they are used in different industries. CO_2 so released is added to the atmosphere and would have proved harmful to living organisms, but in photosynthesis green plants take in CO_2 and release O_2 thus purifying the air.

(3) **Conversion of radiant energy :** It changes radiant energy into chemical energy. All organisms use chemical energy for their activities.

(4) **Plant products :** A number of useful products are obtained from plants, they are synthesized by plants through photosynthesis. Important plant products are fire wood, timber, oils, gums resins, rubber, cork, tannins, alkaloids or drugs, fibres, etc.

(5) **Productivity :** Rising of photosynthetic capacity will reduce the effect of excess carbon dioxide generation. It will increase crop productivity for feeding the rising human and cattle population. Therefore, methods of photosynthetic enhancement are being studied.

5.11 EXPERIMENTS

Experiment : 1

Ganong's light screen : This simple experiment confirms that light is necessary for photosynthesis. It is a metallic structure with a specific cut out. When a destarched leaf is covered by the screen and placed in sunlight, photosynthesis occurs. The leaf is then taken out, treated with ethanol and then with iodine. Only the exposed parts of the leaf turn blue. The covered parts remain unstained as no starch could be formed there due to non-availiability of light.

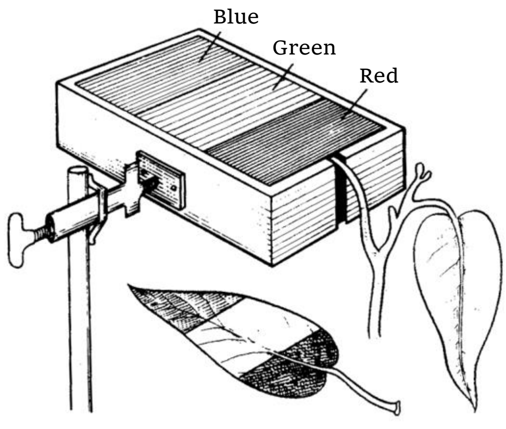
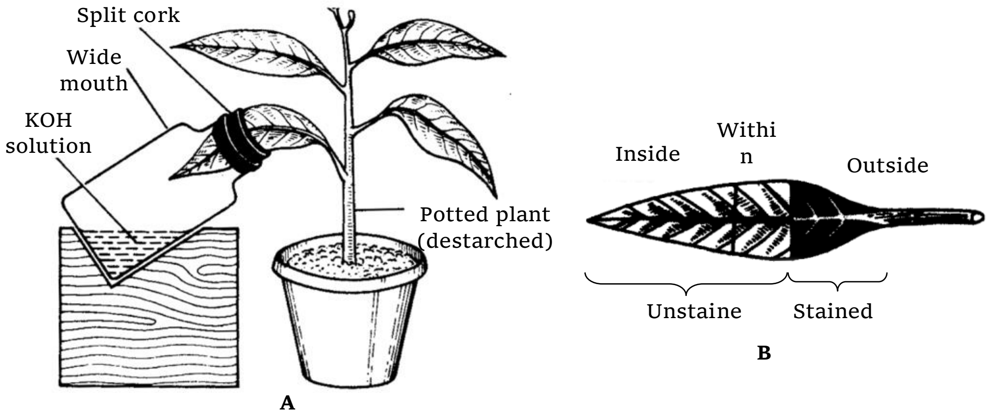


Fig : Ganong's light screen to study the effect of light on the photosynthesis

Experiment : 2

Moll's half leaf experiment : This experiment is designed to prove that CO_2 is necessary for photosynthesis. A plant is destarched by keeping in dark. A leaf of this plant is half inserted in a vial or bottle containing some KOH solution through a split cork. If the leaf is detached, its petiole should be dipped in a petridish containing water. The apparatus is kept in sunlight. After a few hours the leaf is taken out and put in ethanol for removing chlorophyll. It is, then treated with iodine. The part of the leaf lying outside the cork is stained blue confirming the occurrence of photosynthesis in that region.

The part of the leaf that lies inside the vial remains unstained because no photosynthesis occurs in that part due to non-availability of CO_2. The part which lies in between the cork pieces also remains unstained because it neither gets light nor CO_2.



Experiment : 3

To show that chlorophyll is necessary for photosynthesis : Select a potted Croton or Coleus plant having variegated leaves. Select a few young leaves and sketch the extent of the green as well as other colours of these leaves on a piece of paper. Place the pot in the sunlight for a few hours and then take starch test. Only chlorophyll containing cells give positive starch test.

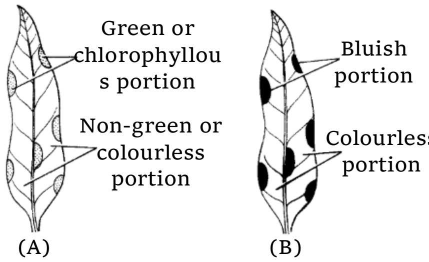


Fig : Experiment to show that chlorophyll is essential for photosynthesis (A) Variegated leaf before experiment, (B) Variegated leaf

Experiment : 4

To show that oxygen is evolved in photosynthesis by green plants : Water-weeds like *Hydrilla* or *Ceratophyllum* are best for this experiment. Take some water-weeds and cut the bases of the plant and tie them with a thread. Put them in a beaker containing water and invert a funnel over them as shown in the figure. Fill a test tube with water and invert it over the nozzle of the funnel so that no air-bubble gets in. Expose the whole apparatus to light.

It is seen that some bubbles come out continuously and are collected at the top of test tube by displacing the water.

On testing the gas it is found to be oxygen. This evolved oxygen is produced by the green aquatic plant in the process of photosynthesis.

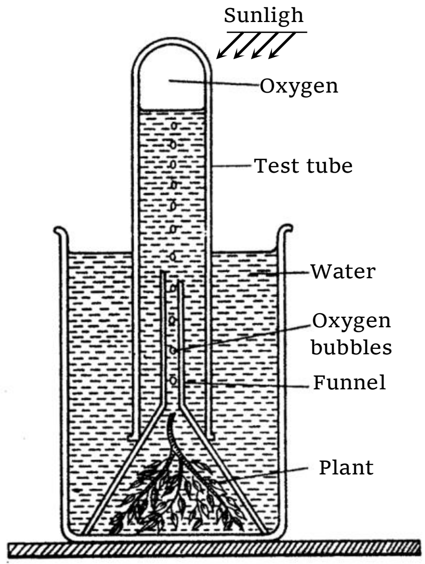


Fig : Liberation of oxygen in photosynthesis by an aquatic plant

Experiment : 5

To show that starch is formed in photosynthesis : Detach a destarched green leaf from a plant. Boil the leaf in water and then boil in 70% ethyl alcohol for 15 minutes (In a water bath). The leaf becomes colourless as chlorophyll gets dissolved in alcohol. Wash the leaf with water and test it with iodine solution. It gives negative starch test. Now keep the plant in light for 8 hours and again test it for starch. The leaf becomes bluish black or bluish-purple indicating the presence of starch.

Important Tips

- **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.
- Actual reduction of CO_2 to carbohydrates is independent of light, i.e., occurs in presence or absence of light, but production of assimilatory powers (ATP and $NADPH_2$) needs light and is light dependent.
- **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.
- Cyclic photophosphorylation is the most effective anaerobic phosphorylation mechanism.
- 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.
- NAD is considered to be the "Universal hydrogen acceptor".
- Non-cyclic photophosphorylation or Z-scheme is inhibited by **CMU** and **DCMU**.
- 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).
- **Cytochromes :** The terms was coined by Keilin (1925) though the biochemicals were discovered by Mac Munn (1866).
- Intensity of light can be measured by **Luxmeter**.
- Isolated chlorophyll 'a' in pure form emits red colour. It is called **fluoresence**.
- Phytochrome is a proteinaceous pigment found in low concentrations in most plant organs. Which absorbs red (P_R or P_{660}) and far red (P_{fR} or P_{730}) light.
- Anthoxanthins and Anthocyanin pigments are also soluble in water and found in cell sap, due to which white, yellow and orange colour produce in flowers.

***

ASSIGNMENT

HISTORY OF PHOTOSYNTHESIS

Basic Level

1. The law of limiting factor for photosynthesis was enunciated by
   (a) Blackmann (b) Hill (c) Ruben (d) Kamen
2. The 'Z' scheme of photosynthesis was proposed by
   (a) Hill and Bendall (b) Emerson (c) Arnon (d) Rabinowitch and Govindjee
3. Who revealed the chemical composition of chlorophyll carotene and xanthophyll
   (a) Govindjee (b) Willstatter and Stoll (c) Park and Biggins (d) Mayer and French
4. Who proposed the 'law of limiting factor' as the 'law of minimum'
   (a) Blackmann (b) Hill (c) Liebig (d) Priestley
5. The law of limiting factor in photosynthesis was criticised by
   (a) James and Harder (b) Mayer and Anderson (c) Willstatter and Stoll (d) Hill and Scarisbrick
6. "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
7. "Photosynthesis is the conversion of light energy within a plant" was first stated by
   (a) Willstatter and Stoll (b) Mayer and Anderson (c) Benson and Calvin (d) Robert Mayer
8. "*Thylakoid"* name was given by
   (a) Arnon (b) Park and Biggins (c) Park and Fortan (d) Manke
9. The researches on photosynthesis started
   (a) In the 17^{th} century (b) In the 18^{th} century
   (c) In the 19^{th} century (d) In the early 20^{th} century
10. "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
11. Scientist who first discovered the role of light in photosynthesis
    (a) Sachs (b) Priestley (c) Senebier (d) Ingenhousz
12. The process of photophoshorylation was discovered by
    (a) Calvin (b) Arnon (c) Priestley (d) Warburg
13. The first experiment on photosynthesis in flashing light were carried out by
    (a) F.F. Blackmann (b) Robert Emerson and Arnold
    (c) Melvin Calvin (d) Robert Hill

14. Who received the Nobel Prize for working out the early carbon pathway of photosynthesis

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

15. Who invented the enhancement effect on photosynthesis

(a) Ruben (b) Calvin (c) Emerson (d) Arnon

16. 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

17. Action spectrum of photosynthesis was first studied by

(a) Blackmann (b) Van Mayer (c) Engelmann (d) Boussingault

18. Hypothesis for oxygen coming from water was put forward by

(a) Hill (b) Warburg (c) Blackmann (d) Mendel

19. The two pigment system theory of photosynthesis was proposed by

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

20. C_4-cycle was discovered by

(a) Hatch and Slack (b) Calvin (c) Hill (d) Arnon

21. ATP formation in chloroplast and mitochondrion is explained by

(a) Cholondny-Went model (b) Chemi-osmotic theory of Mitchell

(c) Munch’s mass flow theory (d) Relay pump theory of Godlewski

22. Who first of all indicated that water is electron donor in photosynthesis

(a) Arnon (b) Calvin (c) Blakeslee (d) Van Niel

23. Melvin Calvin is associated with

(a) EMP pathway (b) Kreb’s cycle

(c) Dark reactions of photosynthesis (d) Light reaction of photosynthesis

24. The term ‘chromatophore’ was coined by

(a) Schmitz (b) Comparethi (c) W. Pfeffer (d) Singer and Nicolsan

25. This scientist suggested that there are two stages in photosynthesis, dark and light

(a) Melvin Calvin (b) Martin Ruben (c) F.F. Blackmann (d) Stephen Hales

26. Term ‘Assimilatory powers’ was given by

(a) Emerson (b) Lewis (c) Arnon (d) Ruben and Kamen

27. 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

Advance Level

28. 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) Von Helmont (d) Darwin

29. 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

30. The scientist, who proved that bacteria use H_2S gas and CO_2 to synthesize carbohydrate, is

(a) Van Niel (b) Ruben (c) Jean Senebier (d) Julius Robert Mayer

31. The oxygen produced during photosynthesis comes from photolysis of water was first time proved by

(a) Ruben and Kamen (b) Robert Mayer (c) Melvin Calvin (d) Blackmann

PHOTOSYNTHESIS APPARATUS AND GENERAL

Basic Level

32. Chlorophyll molecules has the structure like

(a) Monopyruvic (b) Dipyruvic (c) Tripyruvic (d) Tetrapyruvic

33. Chlorophyll 'e' is generally present in

(a) Thallophytes (b) Rhodophytes (c) Mycophytes (d) Xanthophytes

34. A pigment which absorbs red and far-red light is

(a) Phytochrome (b) Carotene (c) Cytochrome (d) Xanthophyll

35. The value of Q_{10} for photosynthesis is

(a) 4 (b) 6 (c) 7 (d) 2 to 3

36. Which of the following is correct for photosynthesis

(a) Biological oxidation process (b) Photochemical catabolic process

(c) Photo-oxidative metabolism (d) Biological photometabolism

37. Which of the following is the non-polar part of chlorophyll

(a) Phytol (b) Porphyrin (c) Pyrrol (d) None of the above

38. In prokaryotes, the photosynthetic lamellae remain in

(a) Group (b) Isolated

(c) Associated with nucleus (d) None of the above

39. In normal chloroplast, the percentage of chlorophyll is

(a) 50% (b) 75% (c) 5–10% (d) 95%

40. Photosynthetic pigments in chloroplast are embedded in membrane of

(a) Thylakoids (b) Photoglobin

(c) Matrix (d) Envelope of chloroplast

41. Which of the following equation can be more appropriate for photosynthesis

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

(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 these

42. In photosynthesis, plants

(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

43. Which fractions of the visible spectrum of solar radiations are primarily absorbed by carotenoids of the higher plants

(a) Violet and blue (b) Blue and green (c) Green and red (d) Red and violet

44. Thylakoids, present in chloroplast contains a cellular organelle in which there occurs light reaction. The organelle is

(a) Grana (b) Stroma (c) Lamellae (d) Outer membrane

45. Which pigment is present universally in all green plants

(a) Chlorophyll–*a* (b) Chlorophyll–*b* (c) Chlorophyll–*c* (d) Chlorophyll–*m*

46. Which one of the following statements about cytochrome P_{450} is wrong

(a) It has an important role in metabolism

(b) It contains iron

(c) It is a coloured cell

(d) It is an enzyme involved in oxidation reactions

47. P_{700} is a special form of which pigment

(a) Chlorophyll *b* (b) Carotenes (c) Chlorophyll *a* (d) Phycobilins

48. 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

(a) *Aa, Bd, Cc, Dd* (b) *Aa, Bc, Cd, Da* (c) *Ac, Bd, Ca, Db* (d) *Ad, Bd, Cc, Da*

49. Compensation point refers to

(a) Little photosynthesis

(b) Beginning of photosynthesis

(c) Rate of photosynthesis equals to the rate of respiration

(d) None of these

50. Plants are known as purifiers of air due to process of

(a) Respiration (b) Photosynthesis (c) Transpiration (d) Desiccation

51. Which one is Cu^{++} containing pigment

(a) Ferredoxin (b) Plastocyanin (c) Plastoquinone (d) Cytochrome

52. The most vital process for the existance of life on earth is

(a) Communication in animals (b) Photosynthesis by plants

(c) Reproduction in plants and animals (d) Respiration in animals

53. The separation of water into hydrogen and oxygen during photosynthesis is aided by

(a) Nitrogen and phosphorous compounds (b) *Mn* and chloride ions

(c) *Fe* and high turgor pressure (d) *Cu* and *Mo* atoms

54. Sugar produced in photosynthesis is converted into starch in

(a) All plants (b) Majority of plants (c) Algae only (d) Bacteria only

55. The core metal of chlorophyll is

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

56. The ultraviolet radiations from the sun cause reactions that produce

(a) Carbon monoxide (b) Carbon dioxide (c) Ozone (d) Fluorides

57. 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

58. Chloroplast fixes

(a) O_2 (b) H_2 (c) CO_2 (d) N_2

59. Which pigment is absent in chloroplast

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

60. Two chief functions of leaves are

(a) Photosynthesis and respiration (b) Photosynthesis and transpiration

(c) Transpiration and respiration (d) Respiration and digestion

61. 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

62. Quantasomes contain

(a) 200 chlorophyll molecules (b) 230 chlorophyll molecules

(c) 250 chlorophyll molecules (d) 300 chlorophyll molecules

63. The gas absorbed during photosynthesis is

(a) Oxygen (b) Nitrogen (c) Ammonia (d) Carbon dioxide

64. Which branch of Botany is concerned with the study of photosynthesis

(a) Ecology (b) Psycology (c) Plant physiology (d) Embryology

65. The process of photosynthesis takes place in

(a) Roots only (b) Shoot only

(c) All the cells of plant (d) Chlorophyll containing cells only

66. Photosynthesis is a

(a) Exothermic process (b) Exergonic process (c) Anabolic process (d) Catabolic process

67. During photosynthesis, the oxygen in glucose comes from

(a) Water (b) Carbon dioxide

(c) Both from CO_2 and water (d) Oxygen in air

68. The brown colour of some algae is due to the presence of pigments

(a) Chlorophyll (b) Phycocyanin (c) Carotene (d) Fucoxanthin

69. All plastids have essentially same structure because

(a) They have to perform same function

(b) They are localized in aerial parts of plants

(c) All plastids store starch, lipid and proteins

(d) One type of plastid can be differentiated into another type of plastid depending on cell requirements

70. Compensation point is

(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

71. 85–90% of all photosynthesis of the world is carried out by

(a) Shrubs (b) Herbs

(c) Oceanic algae (d) Trees with large branches

72. The plant *Cuscuta* shows maximum photosynthesis in

(a) Red light (b) Blue light

(c) Green light (d) No photosynthesis at all

73. 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

74. Blue-green algae shows

(a) Chlorophyll '*a*' (b) Chlorophyll '*b*' (c) Both (a) and (b) (d) None of the above

75. Which one is the precursor of chlorophyll

(a) Bacteriochlorophyll (b) Bacterioviridin (c) Tryptophane (d) Chlorophyllide

76. Which of the following pigment is soluble in water

(a) Chlorophyll (b) Carotene (c) Anthocyanin (d) Xanthophyll

77. 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

78. Intact chloroplast from green leaves can be isolated by

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

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

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

80. The basic structure of all chlorophyll comprises of

(a) Porphyrin system (b) Cytochrome system (c) Plastocyanin system (d) Flavoproteins only

81. The emperical formula for chlorophyll '*a*' is

(a) $C_{35}H_{72}O_5N_4Mg$ (b) $C_{55}H_{70}O_6N_4Mg$ (c) $C_{55}H_{72}O_5N_4Mg$ (d) $C_{54}H_{70}O_6N_4Mg$

82. Which of the following is the bye-product of photosynthesis

(a) Potential energy (b) Energy (c) Carbon dioxide (d) Oxygen

83. During photosynthesis

(a) Both CO_2 and water get oxidized (b)Both CO_2 and water get reduced

(c) Water is reduced and CO_2 is oxidized (d)Carbon dioxide gets reduced and water get oxidised

84. Chlorophyll '*b*' is characterised by the side group of

(a) Methyl (b) Formyl (c) Phytol (d) Keto

85. Magnesium is required to form the molecule of

(a) Plastocyanin (b) Ferridoxin (c) Chlorophyll (d) None above

86. The molecular weight of chlorophyll *a* is

(a) 891 (b) 907 (c) 893 (d) 889

87. Maximum amount of organic matter that can be produced on earth/year by photosynthesis

(a) 2×10^{10} tons (b) 2×10^{9} tons (c) 2×10^{11} tons (d) 2×10^{19} tons

88. If the contents of a mass of living cells are carefully fractionated, which of the following fractions can be called 'alive'

(a) Chloroplast (b) Cell wall

(c) Ribosome (d) Endoplasmic reticulum

89. Which enzyme is most abundantly found on earth

(a) Catalase (b) Invertase (c) Nitrogenase (d) Rubisco

90. Photosynthesis will proceed upto

(a) Limit of light (b) Limit of wind (c) Limit of moisture (d) None of the above

91. 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

92. Solarization of chlorophyll is

(a) Photo-oxidation (b) Photoreduction (c) Oxido-reduction (d) None of the above

93. What is the quantum yield of photosynthesis

(a) 8% (b) 12% (c) 9% (d) 33%

94. Chlorophyll '*a*' is found in

(a) All oxygen releasing photosynthetic forms (b) All plants except fungi

(c) All higher plants that photosynthesize

(d) All photosynthetic prokaryotes and eukaryotes

95. How much percentage of absorbed water is used in photosynthesis

(a) 1% (b) 5% (c) 10% (d) 90%

96. How much energy is utilised in the synthesis of one molecule of glucose

(a) 673 kcal (b) 686 kcal (c) 666 kcal (d) 696 kcal

97. $C_{40}H_{56}$ is the emperical formula of

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

98. $C_{40}H_{56}O_2$ is an emperical formula of a

(a) Xanthophyll (b) Carotene (c) Anthocyanin (d) Chlorophyll

99. Grana are absent in the chloroplasts of

(a) Shrubs (b) Herbs (c) Algae (d) Trees

100. Chlorophyll consists of

(a) A head of phytol and tail of four pyrrole rings

(b) A head of linked carbons and tail of four pyrrole rings

(c) A head of four pyrrole rings and tail of linked nitrogens

(d) A head of four pyrrole rings and an alcoholic phytol tail

101. Plants with high light compensation point are

(a) C_3 plants (b) Sun plants (c) Shade plants (d) Mesophytes

102. Chlorophyll is

(a) Soluble in organic solvents (b) Soluble in water

(c) Soluble in both organic solvents and water (d) None of the above

103. The role of phycobilins in photosynthesis is to

(a) Absorb and transfer energy to chlorophyll

(b) Donate electrons to the electron transport system

(c) Fix carbon dioxide (d) Carry hydrogen or electrons

104. Starch containing plastids are

(a) Amyloplasts (b) Leucoplasts (c) Chloroplasts (d) Chromoplasts

105. Intensity of light can be measured by

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

106. Importance of photosynthesis is due to

(a) Synthesis of food (b) Purification of atmosphere

(c) Provided vast resources of energy (d) All of the above

107. For synthesis of one glucose molecule, the number of ATP required are

(a) 9 ATP for C_3 cycle and 20 ATP for C_4 cycle

(b) 18 ATP for C_3 cycle and 30 ATP for C_4 cycle

(c) 22 ATP for C_3 cycle and 35 ATP for C_4 cycle

(d) 24 ATP for C_3 cycle and 36 ATP for C_4 cycle

108. Chlorophyll *a* is not found in

(a) Algae (b)Photosynthetic bacteria(c)Both (a) and (b) (d) Bryophytes

109. The approximate dimension of chlorophyll porphyrin ring is

(a) 1 Å square (b) 5 Å square (c) 10 Å square (d) 15 Å square

110. During the course of photosynthesis

(a) ATP is formed

(b) ATP is not formed

(c) Oxygen evolved comes from carbon dioxide

(d) Water is required as medium but it does not take part in photosynthetic reactions

111. In angiosperms, synthesis of chlorophyll occurs in presence of

(a) Phytochrome (b) Light (c) Cytochrome (d) None of the above

112. In photosynthesis, energy for passage of electron is the one that is absorbed by

(a) Chlorophyll (b) RuBP (c) Water (d) ATP

113. Reaction centre of photosynthesis is formed of

(a) Chl *b* (b) Chl *a* (c) Carotene (d) Xanthophyll

114. Carotenes protect plants from

(a) Photooxidation (b) Desiccation (c) Photorespiration (d) Photosynthesis

115. Photolithotrophs (photoautotrophs) obtain energy from

(a) Radiations and carbon from inorganic compounds

(b)Radiations and carbon from organic compounds

(c) Organic compounds (d) Inorganic compounds

116. RUBISCO content of chloroplast is

(a) 20% (b) 5% (c) 11% (d) 16%

117. The detectable end product of photosynthesis is

(a) Glucose (b) Fructose 1,6 diphosphate

(c) Ribulose phosphate (d) Starch

118. Photosynthesis is

(a) Oxidative, exergonic, catabolic (b)Reductive, endergonic, anabolic

(c) Reductive, exergonic, anabolic (d) Reductive, endergonic, catabolic

119. Total amount of the dry weight of photosynthate produced by all type of plants per annum is

(a) 1.7 million tonnes (b) 17 million tonnes (c) 170 million tonnes (d) 1700 million tonnes

120. What is the unique process which has supported life on this planet

(a) N_2-fixation (b) Photosynthesis (c) Protein synthesis (d) Respiration

121. Which group is not alike

(a) Enzyme and protein synthesis (b) Osmosis and diffusion

(c) Photosynthesis and respiration (d) Growth and movement

122. Which one of the following statements is correct for chlorophyll *a*

(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

123. The main difference between the molecules of chlorophyll *a* and *b* is

(a) Chlorophyll *a* has an aldehyde group while chlorophyll *b* has a methyl group

(b) Chlorophyll *a* has a methyl group while chlorophyll *b* has an aldehyde group

(c) The phytol tail is absent in chlorophyll *a* and is present in chlorophyll *b*

(d) The porphyrin group in chlorophyll *b* has no binding site but a binding site is present in chlorophyll *a*

124. Quantasomes are found in

(a) Surface or cristae (b) Surface of plasma membrane

(c) Surface of nuclear membrane (d) Surface of thylakoids

125. Photosynthesis has two reaction complexes, one followed by the other. The second reaction complex

(a) Traps light energy (b) Synthesis starch

(c) Functions in the presence of light (d) Fixes carbon dioxide

126. Chlorophyll *b* is

(a) $C_{54}H_{70}O_6N_4Mg$ (b) $C_{55}H_{70}O_6N_4Mg$ (c) $C_{55}H_{72}O_5N_4Mg$ (d) $C_{45}H_{72}O_5N_4Mg$

127. Maximum solar energy is trapped by

(a) Planting trees (b) Cultivating crops

(c) Growing algae in tanks (d) Growing grasses

128. When day light hours are increased, the rate of photosynthesis

(a) Increases (b) Decreases (c) Remains unchanged (d) None of the above

129. Translocation of carbohydrate nutrients usually occurs in the form of

(a) Glucose (b) Maltose (c) Starch (d) Sucrose

130. Which of the following trees will die first

(a) Deciduous (b) Pruned (c) Hollowed trunk (d) Girdled

131. The size of chlorophyll molecule is

(a) Head $15 \times 15\,Å$, tail 25Å (b) Head $20 \times 20\,Å$, tail 25Å (c) Head $15 \times 15\,Å$, tail 20Å (d) Head $10 \times 12\,Å$, tail 15Å

132. Maximum starch is manufactured by

(a) Spongy parenchyma (b) Palisade parenchyma (c) Guard cells (d) Vascular tissue

133. Chlorophyll *b* differs from chlorophyll *a* in that it does not

(a) Become oxidised (b) Become reduced

(c) Become excited (d) Produce excited electrons

134. Plants do not store carbohydrate as glucose but do so as starch because glucose

(a) Is unstable (b) Attracts herbivores

(c) Will change nucleic acids (d) Alters osmotic balance

135. Rate of photosynthesis is

(a) Equal to that of respiration (b) Less than that of respiration

(c) Depends upon chlorophyll content (d) Faster than that of respiration

136. In aquaria, green plants are grown for

(a) CO_2 (b) Fish food (c) Oxygen (d) Both (a) and (b)

137. During daylight hours, the rate of photosynthesis is higher than that of respiration, and the ratio of oxygen produced to that of consumed is

(a) 1 : 1 (b) 10 : 1 (c) 50 : 1 (d) 5 :1

138. For each molecule of glucose formed in plants, the number of molecule of ATP and $NADPH_2$ required are respectively

(a) 12 and 18 (b) 18 and 12 (c) 15 and 10 (d) 33 and 22

139. 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

140. 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

Advance Level

141. Which of the following is black-yellow pigment of carrot roots

(a) Alpha-carotene (b) Beta-carotene (c) Violoxanthin (d) Fucoxanthin

142. Which one of the following elements is required for photosynthetic oxygen evolution

(a) Copper (b) Iron (c) Manganese (d) Zinc

143. In chlorophyll *'a'* third carbon of second pyroll ring is attached with

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

144. The use of solar cooker by man is copying of which one by the following processes

(a) Photosynthesis (b) Respiration (c) Guttation (d) Photorespiration

145. How much energy in terms of ATP equivalents is consumed in the photosynthetic production of a mole of hexose

(a) 36 ATP eq. (b) 38 ATP eq. (c) 40 ATP eq. (d) 54 ATP eq.

146. 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

147. In presence of light, green plants convert carbon dioxide and water into food stuffs. Which of following is likely to be the first substance that a green plant makes in photosynthesis

(a) A simple sugar (b) Starch (c) Cellulose (d) Fat

148. In blue-green algae photosystem-II contain an important pigment concerned with photolysis of water it is called

(a) β carotene (b) Chlorophyll '*b*' (c) Cytochrome '*c*' (d) Phycocyanin

LIGHT REACTION

Basic Level

149. In the electron transport system, the reduced coenzymes are regenerated by

(a) Loss of hydrogen (b) Loss of electron (c) Addition of oxygen (d) None of the above

150. The light energy passes in the form of

(a) Photo ions (b) Photons (c) Photosomes (d) All of the above

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

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

152. Unidirectional flow of electrons in photophosphorylation takes place in

(a) Cyclic (b) Non-cyclic (c) Pseudocyclic (d) All of the above

153. In light reaction of photosynthesis, chlorophyll is subjected to

(a) Destruction (b) Permanent reduction

(c) Oxidation and reduction (d) Neutralization

154. Which type of phosphorylation takes place in photosynthesis

(a) Cyclic (b) Non-cyclic (c) Both (a) and (b) (d) None of the above

155. Ferredoxin is a component of

(a) Hill reaction (b) Photosystem–I (c) P – 680 (d) Photosystem–II

156. Chlorophyll molecule (PS-II) when excited and electron so released passes first into

(a) Plastoquinone (b) Plastocyanin

(c) Ferredoxin (d) Ferredoxin reducing substrate

157. In photosynthesis light energy is utilized by

(a) Converting *ATP* into *ADP* (b) Changing CO_2 into carbohydrate

(c) Converting ADP into ATP (d) All of the above

158. Assimilatory power refers to

(a) Generation of ATP and NADPH (b) Reduction of CO_2

(c) Splitting of water (d) Disintegration of plastids

159. In which of the following the rate of photosynthesis is decreased and is known as red drop

(a) Blue light (b) Green light

(c) Red light more than 680 *nm* (d) Red light less than 680 *nm*

160. Pigment system-I receives radiant energy and releases electron

(a) Chlorophyll – 683 (b) Chlorophyll – 673 (c) Chlorophyll – 695 (d) P – 700

161. ATP formation in photosynthesis is known as

(a) Phosphorylation (b) Photophosphorylation

(c) Oxidative phosphorylation (d) None of the above

162. The process in which water is split during photosynthesis and is essential for photosynthesis

(a) Photolysis (b) Hydrolysis (c) Plasmolysis (d) Haemolysis

163. The most effective wavelength of visible light in photosynthesis is in the region of

(a) Violet (b) Green (c) Yellow (d) Red

164. Photosystem-II occurs in

(a) Stroma (b) Grana

(c) On surface of mitochondria (d) On cytochrome

165. Energy transfer in photosynthesis occurs as

(a) Phycoerythrin $\rightarrow$ Phycocyanin $\rightarrow$ Carotenoid $\rightarrow$ Chlorophyll *a*

(b) Chlorophyll *b* $\rightarrow$ Carotenoid $\rightarrow$ Phycoerythrin $\rightarrow$ Chlorophyll *a*

(c) Phycocyanin $\rightarrow$ Phycoerythrin $\rightarrow$ Carotenoid $\rightarrow$ Chlorophyll *a*

(d) Chlorophyll $\rightarrow$ Carotenoid $\rightarrow$ Phycocyanin $\rightarrow$ Chlorophyll *a*

166. Hill reaction occurs in

(a) High altitude plants (b) Total darkness

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

167. Emerson effect explain the phenomenon of

(a) Transpiration (b) Absorption of water by roots

(c) Photosynthesis (d) Respiration

168. O_2 evolution is directly associated with

(a) PS I (b) PS II (c) Phytochrome (d) Phycocyanin

169. In photosynthesis, energy from light reaction to dark reaction is transferred in the form of

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

170. What percentage of usable radiant energy entering a reaction site of photosynthesis is converted to potential energy

(a) 10% (b) 20% (c) 35% (d) 42%

171. The light absorbed by the chlorophyll is at the wavelength of

(a) 400 *nm* (b) 500 *nm* (c) 600 *nm* (d) 660 *nm*

172. Which of the following conditions are favourable for cyclic photophosphorylation

(a) Anaerobic condition (b) Aerobic and optimum light

(c) Aerobic and low light intensity (d) Anaerobic and low light intensity

173. The electron transport chain of photosynthetic process is

(a) In the stroma of the chloroplast (b)Bound to the thylakoid membranes

(c) Present in the outer membrane of the chloroplast (d)Present in mitochondria

174. Photosynthetically active radiation (PAR) represents the following range of wavelength

(a) 340 – 450 *mm* (b) 400 – 700 *mm* (c) 500 – 600 *mm* (d) 450–950 *mm*

175. The wavelength of light most absorbed during photosynthesis is

(a) 440 *nm* (b) 550 *nm* (c) 660 *nm* (d) 700 *nm*

176. Photosynthetic unit is

(a) Glyoxysome (b) Spherosome (c) Microsome (d) Quantasome

177. Chlorophyll '*a*' and '*b*' shows maximum absorption in

(a) Blue region (b) Red region

(c) Blue and red regions (d) Yellow and violet regions

178. Where the primary photochemical reaction occurs in chloroplast

(a) Stroma (b) Periplast cavity (c) Quantasome (d) Inner membrane

179. The chlorophylls absorb visible light in the region of following wavelengths

(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

180. The process in which excess energy is lost by light waves is called

(a) Fluorescence (b) Photophosphorylation (c) Photolysis (d) Photooxidation

181. The photosynthetic pigments viz, erythrolable, chlorolable and cyanolable respectively are

(a) Green, Red, Blue (b) Red, Blue, Green (c) Red, Green, Blue (d) Blue, Green, Red

182. Which process is related with photosynthesis

(a) Phosphorylation (b) Translation (c) Transcription (d) None of these

183. The full expansion of NADP is

(a) Nicotinamide adenine diphosphate (b) Nicotinamide adenosine diphosphate

(c) Nicotinamide adenine dinucleotide phosphate

(d) Nicotinamide adenosine dinucleotide phosphate

184. Photolysis of water takes place in

(a) Calvin cycle (b) Glycolysis (c) Light phase (d) Dark phase

185. In which stage of photosynthesis, light is directly necessary

(a) For electron exitation (b) For reduction of CO_2

(c) For regulating photosystem (d) For cyclic photophosphorylation

186. The source of O_2 liberated in photosynthesis in green plants is

(a) Photosynthetic enzyme (b)Carbohydrate present in leaf

(c) Water (d)Carbon dioxide

187. NADP is converted into $NADPH_2$ in

(a) Photosystem–I (b) Non-cyclic photophosphorylation

(c) Calvin cycle (d) Photosystem–II

188. When a cell convert light energy into chemical energy, which of the following reaction would take place

(a) ADP + IP = ATP (b) ATP – IP = ADP (c) AMP + IP = ADP (d) GDP + IP = GTP

189. 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

190. Wavelength of green light is

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

191. In cyclic photophosphorylation which one of the following is formed

(a) ATP (b) NADP and ATP

(c) $NADH_2$ and O_2 (d) $NADPH_2$ ATP and O_2

192. $NADPH_2$ is generated through

(a) Glycolysis (b) Photosystem–I

(c) Photosystem–II (d) Anaerobic respiration

193. Photophosphorylation differs from oxidative phosphorylation in

(a) It takes place in light (b)ATP is formed

(c) Cytochrome participates (d) All of the above

194. Quantasomes are present in

(a) Pigment system–I (b) Pigment system–II (c) Both (a) and (b) (d) None of the above

195. Which of the chlorophyll type ejects the electron during photophosphorylation

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

196. Which colour of spectrum is least effective in photosynthesis

(a) Green (b) Red (c) Blue (d) Violet

197. Fluorescent chlorophyll '*a*' occurs in

(a) PS – I (b) PS – II (c) Both (a) and (b) (d) Stroma

198. The decrease in yield of photosynthesis in the presence of red light becomes increased to normal when it is supplemented with blue light. This phenomenon is termed as

(a) Blackmann's effect (b) Emerson's effect (c) Englemann's effect (d) Hill's effect

199. When the two pigment systems absorb light, in what direction does energy flow between them

(a) PS–I $\rightarrow$ PS–II (b) PS–II $\rightarrow$ PS–I (c) PS–II $\neq$ PS–I (d) None of the above

200. The two light reactions when absorb light drive the flow of electrons against an electrochemical gradient from

(a) $-1.1\,volt$ to $+0.8\,volt$ (b) $+0.8\,volt$ to $-0.3\,volt$ (c) $+2.0\,volt$ to $+5.2\,volt$ (d) $-0.5\,volt$ to $+25\,volt$

201. The energy of a 'mole' of light quanta is 72 *kcal* in blue region at 400 *nm* and 41 *kcal* in red region at 700 *nm*. How much light energy would be required under standard conditions to make 1 mole of glucose costing 686 *kcal*

(a) 1986 *kcal* (b) 1968 to 3456 *kcal* (c) 2620 to 3456 *kcal* (d) 1980 *kcal*

202. 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) Ferredoxin (d) Plastocyanin

203. Emmerson defined 'red drop' as a decline in photosynthesis also termed Emmerson's effect. It appears at

(a) 460 *nm* wavelength (b) 630 *nm* wavelength

(c) 680 *nm* wavelength (d) > 680 *nm* wavelength

204. Photosystem–I contains

(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}

205. Chlorophyll *a* molecule lost 1 electron from its outer orbit and gain

(a) Negative charge (b) Becomes neutral (c) Positive charge (d) None of the above

206. The life of all excited chlorophyll molecules is

(a) Less than 0.01 second (b)More than 0.01 second

(c) 10 seconds (d)1 second

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

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

208. During photochemical reactions of photosynthesis

(a) Liberation of oxygen takes place

(b) Formation of ATP and $NADPH_2$ take place

(c) Liberation of O_2 and formation of ATP and $NADPH_2$ take place

(d) Assimilation of CO_2 takes place

209. Hill's reaction takes place in

(a) Dark (b) Light (c) Dark and light both (d) At any time

210. 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

211. The first event in photosynthesis is

(a) Synthesis of ATP (b)Photoexcitation of chlorophyll and ejection of electron

(c) Photolysis of water (d)Release of oxygen

212. Photophosphorylation is a process in which

(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

213. The role of chlorophyll in photosynthesis is

(a) Absorption of CO_2 (b)Absorption of light

(c) Absorption of light and photochemical decomposition of water (d)Absorption of water

214. Light reaction of photosynthesis takes place in

(a) Grana (b) Stroma (c) ER (d)Cytoplasm

215. What percentage of light energy is utilized in the photosynthesis of higher plants
(a) 1 – 2% (b) 10 % (c) 50 % (d) 100 %

216. What is the role of light in plants
(a) Necessary for photosynthesis (b)Controls growth and movement
(c) Controls distribution of hormones and flowering (d)All of the above

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

218. What is common between photosynthesis and respiration
(a) Cytochrome (b) Light (c) H_2O (d) Temperature

219. 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

220. Pigment system—I conducts
(a) Cyclic photophosphorylation (b) Non-cyclic photophosphorylation
(c) Both (a) and (b) (d) None of the above

221. Pigment system–II is concerned with
(a) Photolysis of water (b) Reduction of CO_2 (c) Flowering (d) None of the above

222. Leaves appear green because they
(a) Reflect green light (b) Absorb green light
(c) Both reflect and absorb green light (d) None of the above

223. Light is necessary during photosynthesis for
(a) Evolution of hydrogen (b)Photolysis of water (c) Heating (d) Opening of stomata

224. Photochemical reaction by excited form of chlorphyll '*a*' takes part in
(a) Metastable triplet state (b)First singlet state (c) Second singlet state (d) Ground state

225. Where do you find cytochromes b_6 and *f*
(a) Chloroplast (b) Lysosomes (c) Ribosomes (d) Mitochondria

226. Quinones are
(a) Mobile electron carriers (b) Enzymes of oxidative phosphorylation
(c) Enzymes of krebs cycle (d) None of the above

227. One photon of blue light contains............*kcal* or light energy
(a) 40 (b) 70 (c) 220 (d) 10

228. How many cytochromes are involved in the electron transport chain
(a) Two (b) Four (c) Five (d) Six

229. In photosynthesis hydrogen is transferred from the 'light' reactions to the 'dark' reactions by
(a) DPN (b) DNA (c) ATP (d) NADP

230. Which pigment system is inactivated in red drop
(a) PS – I and PS – II (b) PS – I (c) PS – II (d) None of these

231. The ingredient required for ATP synthesis is

(a) *Ca* (b) *S* (c) *P* (d) *Fe*

232. In the two light reactions of photosynthesis

(a) PS I produces strong oxidant while PS II a strong reductant

(b) PS I produces strong reductant NADPH while PS II a strong oxidant

(c) PS I emits electrons for PS II.

(d) PS I produces ATP which is not formed by PS II.

233. Which one is dephosphorylation

(a) Fructose 1-phosphate $\rightarrow$ Fructose, 1-6-biphosphate

(b) Fructose, 1-6 biphosphate $\rightarrow$ Fructose 1-phosphate

(c) Fructose 1-phosphate $\rightarrow$ Fructose 6-phosphate

(d) Glucose 6-phosphate $\rightarrow$ Fructose 6-phosphate

234. Ferredoxin in

(a) Phenol (b) Protein (c) Fat (d) Carbohydrate

235. Hill used a dye for his famous Hill reaction

(a) Sulphur green (b) Eosine

(c) Methylene blue (d) Dichlorophenol indophenol

236. Accessory pigments transfer their energy to chlorophyll molecules through

(a) Fluorescence (b) Resonance (c) Radiation (d) Transduction

237. In photosynthetic electron transport system, *Mn* ions are associated with

(a) $CF_0 - CF_1$ complex (b) $Cyt\ b_6 - Cyt\ f$ complex

(c) Oxygen evolving complex (d) Plastoquinone

238. Emerson effect is related to

(a) Decrease in photosynthesis in presence of high light intensity

(b) Decrease in photosynthesis when lights of two different wavelengths are provided together

(c) Increase in photosynthesis in presence of monochromatic light

(d) Increase in photosynthesis when lights of two different wavelengths are provided together

239. Source of protons within the chloroplasts is

(a) Water (b) Excited chlorophyll (c) Carbon dioxide (d) Rubisco

240. The process of photophosphorylation is similar to mitochondrial reaction called

(a) Substrate-level phosphorylation (b)Oxidative phosphorylation

(c) Carbohydrate phosphorylation (d)Hydrolysis of phosphorylated compounds

241. Energy required for ATP synthesis in PS II comes from

(a) Proton gradient (b) Electron gradient

(c) Reduction of glucose (d) Oxidation of glucose

242. In cyclic photophosphorylation the electron released by reaction centre is ultimately accepted by

(a) Ferredoxin (b) $NADP^+$ (c) Reaction centre (d) Plastocyanin

243. Our present day view regarding photosynthesis is that it

(a) Converts light energy into chemical energy (b) Creates useful energy

(c) Fixes CO_2 into carbohydrates (d) Reverses the action of respiration

244. The process for which manganese and chloride ions are required is

(a) Photolysis of water

(b) For transfer of H^+ ion to NADP

(c) For transfer of charge of hydroxyl ion to chlorophyll

(d) None of the above

245. How many molecules of water should be photolysed to form a $NADPH_2$ molecule

(a) 4 (b) 2 (c) 6 (d) 1

246. In photosynthesis, photolysis of water is used in

(a) Reduction of NADP (b) Oxidation of NADP (c) Oxidation of FAD (d) None of these

247. Main pigment involved in transfer of electrons in photosynthesis is

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

248. What are the two peaks of light absorption of Chlorophyll '*a*'. The two peaks are near

(a) 400 and 500 *nm* (b) 430 and 730 *nm* (c) 430 and 660 *nm* (d) 400 and 660 *nm*

249. DCMU is an inhibitor of

(a) PS – I (b) PS – II (c) Calvin cycle (d) Krebs cycle

250. Supply of which of the material to an isolated chloroplast increases O_2 evolution

(a) Water (b) ATP (c) NAD^+ (d) $NADP^+$

251. Which cytochrome ensures a link between reduced end of LR-II (PQ^{--}) and oxidised end of $LR-1(PC^{++})$

(a) $Cyt-c$ (b) $Cyt-a_1$ (c) $Cyt-a_3$ (d) $Cyt-f$

252. 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

253. 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

(a) Stroma (b) Endoplasmic reticulum

(c) Quantasome or thylakoids (Grana) (d) Inner membrane of chloroplast

Advance Level

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

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

255. 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

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

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

(c) If Assertion is true statement but Reason is false

(d) If both Assertion and Reason are false

256. If the photosynthetic yield in blue wavelength is 10 units and that in red wavelength is 40 units; what should be the yield of photosynthesis in combination of two wavelengths, if the effect is synergistic

(a) 30 units (b) 40 units (c) 50 units (d) > 50 units

257. Which photochemical reaction generates strong oxidant and weak reductant

(a) LR – I (b) LR – II

(c) Cyclic photophosphorylation (d) Non-cyclic photophosphorylation

258. What is the common value of PQ (photosynthetic quotient) of a leaf

(a) > 1 (b) < 1 (c) One (d) Zero

259. Which one of the following is due energy currency of the cell or The common immediate source of energy in cellular activity is

(a) Phosphate (b) ATP (c) ADP (d) AMP

260. Englemann (1882) observed accumulation of aerobic bacteria around blue and red illumination of chloroplast in green alga *Cladophora*. He therefore concluded that

(a) Chlorophyll absorbs green light

(b) Absorption spectrum of O_2 evolution is blue and red

(c) O_2 is released from H_2O in light reaction (d) O_2 is released from CO_2 in light reaction

261. Continued evolution of O_2 in suspension of an isolated chloroplast in light in the presence of ferric salt, viologen dyes etc. is called

(a) Emerson’s reaction (b) Hill’s reaction

(c) Blackmann’s reaction (d) Oxygenation

262. The rate of photosynthesis declines in the presence of red light and is increased to normal level when red light is supplemented with

(a) Far-red light (b) Orange light (c) Blue light (d) Ultraviolet light

DARK REACTION

Basic Level

263. The plants growing in dark show yellowing in leaves and elongated internodes, this condition is called as

(a) Etiolation (b) Chlorosis (c) Dechlorosis (d) Dark effect

264. Dark reaction of photosynthesis is called

(a) Aphotic action (b) Black action
(c) Blackmann's reaction (d) None of the above

265. Ribulose phosphate is a

(a) Aldose sugar (b) Ketose sugar (c) Disaccharide (d) Trisaccharide

266. Which of the following is obtained from CO_2 during glucose manufacture

(a) Oxygen (b) Carbon (c) Both (a) and (b) (d) None of the above

267. Which of the enzyme is involved in the conversion of 3PGA to 3PGAL

(a) Triose phosphate dehydrogenase (b) Carboxydismutase
(c) Phosphatase (d) Aldolase

268. The number of carbon atoms is five in

(a) Xylulose (b) Ribose (c) Ribulose (d) All the above

269. Sedohaptulose is a carbohydrate having

(a) 3 carbon atoms (b) 2 carbon atoms (c) 4 carbon atoms (d) 7 carbon atoms

270. Which of the following required for conversion of 3PGAL and dihydroxy acetone phosphate to fructose 1, 6 diphosphate

(a) Transketolase (b) Aldolase (c) Phosphatase (d) Hexokinase

271. First stable product of Calvin cycle has

(a) 2 carbon atoms (b) 3 carbon atoms (c) 4 carbon atoms (d) 6 carbon atoms

272. To form 1 molecular of glyceraldehyde phosphate in Calvin cycle

(a) 9 ATP and 9 $NaOH$ are required (b) 6 ATP and $6NaOH$ are required
(c) 3 ATP and $3NaOH$ are required (d) 9 ATP and $6NaOH$ are required

273. First transitory chemical formed by reaction between CO_2 and *RuBP* is

(a) PGAL / GAP (b) 2 Carboxy, 3-keto, 1-5 biphospho ribotol
(c) PGA (d) Dihydroxy acetone phosphate

274. CO_2 joins the photosynthetic pathway during

(a) Light reaction (b) Dark reaction (c) Photosystem – I (d) Photosystem – II

275. The initial enzyme of Calvin cycle is

(a) Ribulose 1,5 diphosphate carboxylase (b) Triose phosphate dehydrogenase
(c) Phosphopentokinase (d) Cytochrome oxidase

276. During photosynthesis when PGA is changed into phosphoglyceraldehyde, which of the following reaction occur

(a) Oxidation (b) Reduction (c) Electrolysis (d) Hydrolysis

277. Dark reaction of photosynthesis is called so because

(a) It can also occur in dark (b)It does not require light energy

(c) Cannot occur during day time (d)It occurs more rapidly in night

278. Phosphatase enzymes in C_3 cycle participate in

(a) Addition of phosphate

(b) Removal of phosphate

(c) Both the above

(d) The enzyme is not concerned with removal or addition of phosphate

279. In dark reaction, first reaction is the

(a) Carboxylation (b) Decarboxylation (c) Dehydrogenation (d) Deamidation

280. Calvin's cycle is found in

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

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

281. Which of the following is the main product in the photorespiration of C_3 plants

(a) Phosphoglycerate (b) Phosphoglycolate (c) Glycerate (d) Glycolate

282. How many Calvin cycle form one hexose molecule

(a) 2 (b) 6 (c) 4 (d) 8

283. CO_2 acceptor in C_3 plants is

(a) Xylulose – 5 - phosphate (b) 3-phosphoglyceric acid

(c) Ribulose 1, 5 diphosphate (d) Phosphoenol pyruvic acid

284. Which of the following is present in Calvin cycle

(a) Photophosphorylation (b)Oxidative carboxylation

(c) Reductive carboxylation (d) Oxidative phosphorylation

285. Calvin cycle occurs in

(a) Chloroplast (b) Cytoplasm (c) Mitochondria (d) Glyoxysomes

286. The first intermediate formed during photosynthesis is

(a) Fructose 1, 6- diphosphate (b) Ribulose 1, 5-biphosphate

(c) Xylulose –5-phosphate (d) Phosphoglyceraldehyde

287. During dark reaction for fixation of carbon, the three carbon atoms of each molecule of 3-phosphoglyceric acid (PGA) are derived from

(a) *RuBP* only (b) CO_2 only (c) $RuBP + CO_2$ (d) $RuBP + CO_2 + PEP$

288. Which part of the photosynthetic process does not require light and temperature dependent

(a) Hill's reaction (b) Blackmann's reaction (c) Warburg's reaction (d) Emerson's reaction

289. Chloroplast contains maximum quantity of

(a) Pyruvic carboxylase (b) Hexokinase (c) *RuDP* carboxylase (d) None of the above

290. 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 by spinach by Hill

(c) Mesophyll cells of variegated leaves by Arnon

(d) Bundle sheath cells of maize by Hatch and Slack

291. The enzymes enolase catalyses the formation of

(a) Pyruvic acid (b) Phosphoglyceric acid

(c) Phosphoglyceraldehyde (d) None of the above

292. Which of the following have high CO_2 compensation point

(a) C_2 plants (b) C_3 plants (c) C_4 plants (d) Alpine herbs

293. In C_3 plants, the first stable product of photosynthesis during dark reaction is

(a) 3-phosphoglyceric acid (b)Phosphoglyceraldehyde

(c) Malic acid (d) Oxaloacetic acid

294. Dark reaction of photosynthesis take place in

(a) Grana (b) Stroma (c) Matrix (d) Cytoplasm

295. Which of the method is more effective to know the chemical pathway of a physiological process

(a) Titration method (b) Calorimetric method (c) Tracer technique (d) None of the above

296. 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

297. Which of the following product of Hill's reaction are used in Blackmann's reaction

(a) NAD, ATP (b) ATP, $NADH_2$ (c) ATP, $NADPH_2$ (d) ADP, NAD

298. Ribulose diphosphate carboxylase enzyme catalyses the carboxylation reaction between

(a) Oxalocetic acid and acetyl CoA (b) CO_2 and ribulose 1, 5 diphosphate

(c) Ribulose diphosphate and phosphoglyceraldehyde

(d) PGA and dihydroxy acetone phosphate

299. Quanta required for assimilation of one molecule of CO_2 or liberation of the molecule of oxygen are

(a) 16 (b) 8 (c) 4 (d) 2

300. During fixation of one molecule of CO_2 by C_3 plants

(a) 3 ATP and 2 $NADPH_2$ are required (b) 5 ATP and 2 $NADPH_2$ are required

(c) 12 ATP and 2 $NADPH_2$ are required (d) 18 ATP and 12 $NADPH_2$ are required

301. In hydrophytes, the rate of carbon assimilation is

(a) More than land plants (b)Lesser than land plants

(c) Equal in both (d) None of the above

302. The mean photosynthetic rates of C_3 and C_4 plants per dm^2 per hour are respectively

(a) 10 *mg* and 20 *mg* (b) 90 *mg* and 22 *mg* (c) 22 *mg* and 75 *mg* (d) 75 *mg* and 22 *mg*

303. Mesophyll chloroplast of which plant alone is capable of synthesising starch or sucrose

(a) C_3 plant (b) C_4 plant (c) Both (a) and (b) (d) Neither C_3 nor C_4

304. Approximate amount of water on earth which split by photosynthesis once every 2 million years is

(a) 10 million km^3 (b) 15 million km^3 (c) 20 million km^3 (d) 25 million km^3

305. In C_3 plants, phosphoketopentose epimerase is required for converting

(a) Ribose into ribulose (b) Xylulose to ribulose 1.5 $Di\ PO_4$

(c) Erythrose to xylulose (d) None of the above

BACTERIAL PHOTOSYNTHESIS

Basic Level

306. Chromatophores are absent in

(a) Chemosynthetic bacteria (b) Pteridophyta

(c) Gymnosperms (d) Angiosperms

307. Photosynthetic bacteria have pigments in

(a) Leucoplasts (b) Chloroplasts (c) Chromoplasts (d) Chromatophore

308. Bacterial photosynthesis takes place in

(a) Cytoplasm (b) Chromoplast (c) Chloroplast (d) Oxysome

309. The organism which do not release oxygen during photosynthesis is

(a) Algae (b) Bacteria (c) Pteridophytes (d) Mosses

310. Leptothrix is a

(a) Nitrifying bacteria (b) Sulphur bacteria (c) Iron bacteria (d) Hydrogen bacteria

311. Green bacteria contains

(a) Chlorobium chlorophyll – 660 (b) Chlorobium chlorophyll – 650

(c) Both (a) and (b) (d) Chlorobium chlorophyll – 700

312. In the bacterial photosynthesis, hydrogen donor is

(a) H_2S (b) NH_2 (c) H_2O (d) H_2SO_4

313. Which wavelength of light carry out photosynthesis in bacteria

(a) Ultraviolet light (b) Blue (c) Red (d) Far red

314. 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

315. Which photosynthetic bacteria possess both PS I and PS II

(a) Purple sulphur bacteria (b)Cyanobacteria

(c) Purple non-sulphur bacteria (d) Green sulphur bacteria

316. Bacterial photosynthesis contains

(a) PS I (b) PS II (c) Both PS I and PS II (d) None of them

317. Chemosynthetic bacteria obtain energy from

(a) Sun (b) Infra-red rays (c) Organic substances (d) Inorganic chemicals

318. Aerobic bacteria collect near illuminated phytoplankton due to
(a) Manufactured food (b) Light
(c) Oxygen (d) Reduced CO_2 concentration

319. Which organism does not evolve oxygen in photosynthesis
(a) *Anabaena* (b) *Funaria* (c) Higher plants (d) *Rhodospirillum*

320. One of the following is photosynthetic non-sulphur bacterium
(a) *Chlorobium* (b) *Chromatium* (c) *Rhodospirillum* (d) All of these

321. The bacterial photosynthesis is different from that of higher plants as
(a) Energy is not fixed (b) Light is not required
(c) Oxygen is not released (d) A host organism is required

322. In chemosynthesis of NO_2 bacteria, the carbohydrates are formed by
(a) NO_2 and H_2O (b) NH_3 and CO_2 (c) CO_2, H_2O and SO_2 (d) Hydrocarbons

323. Which of the following fixes CO_2 in carbohydrates
(a) Rhodospirillium (b) Nitrobacter (c) Rhizobium (d) Bacillus

Advance Level

324. 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

325. All life on earth derive its energy directly or indirectly from sun except
(a) Mushroom and mould (b)Chemosynthetic bacteria
(c) Symbiotic bacteria (d)Pathogenic bacteria

FACTORS AFFECTING PHOTOSYNTHESIS

Basic Level

326. The plants which perform the act of photosynthesis at $-20°C$ are
(a) Palm plants (b) Mango plants (c) Lichens (d) All of these

327. 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 these

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

329. In cold and foggy areas, the limiting factor is
(a) Temperature (b) Light (c) Both (a) and (b) (d) None of these

330. Blackmann's law of limiting factor is applied to
(a) Growth (b) Respiration (c) Transpiration (d) Photosynthesis

331. What effect would occur on photosynthesis, if the amount of oxygen in the atmosphere decreases
(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

332. At relatively high concentration of CO_2, the rate of

(a) Photosynthesis is increased (b) Osmosis is increased

(c) Ascent of sap is decreased (d) Transpiration is decreased

333. Q_{10} refers to

(a) Quality quotient (b) Temperature quotient

(c) Respiratory quotient (d) Quantum constant

334. The modified view of the law of limiting factor is written as

(a) Relatively limiting factor (b) The factor in relative minimum

(c) The most significant factor (d) Any of the above

335. In nature the photosynthesis should proceed upto the limit of

(a) Light (b) Temperature (c) CO_2 (d) Moisture and wind

336. Plants which can photosynthesize at as low temperature (upto – 35°C) are

(a) Conifers (b) Blue-green algae (c) Xerophytes (d) Tropical plants

337. Which of the following is not required in the synthesis of carbohydrates

(a) CO_2 (b) Chlorophyll (c) Nitrogen (d) Water

338. 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

339. Besides water and light, which is more essential as a raw material for food formation

(a) O_2 (b) CO_2 (c) Mineral salts (d) NAD

340. 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

341. Rate of photosynthesis is independent of

(a) Quality of light (b) Intensity of light (c) Duration of light (d) Temperature

342. Which one of the following is not a limiting factor for photosynthesis

(a) Oxygen (b) Carbon dioxide (c) Chlorophyll (d) Light

343. During monsoon, the rice crop of eastern states of India shows lesser yield due to limiting factor of

(a) CO_2 (b) Light (c) Temperature (d) Water

344. Photorespiration is affected by

(a) Temperature (b) Light intensity (c) CO_2 and O_2 (d) All of these

345. What is called Warburg's effect on photosynthesis

(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 these

Advance Level

346. Blackmann demonstrated that increasing illumination increased the photosynthetic rate upto a point when CO_2 becomes limiting. If light was not limiting, temperature becomes limiting. Emerson found that maximum CO_2 fixation could be achieved with brief flashes of light. Mark the correct statement in the following

(a) Only one factor can be limited in photosynthesis

(b) Photosynthesis consists of a light and dark reaction

(c) The trapping of light by chloroplast is temperature dependent

(d) The trapping of light by chloroplast can coccur only if CO_2 is present

EXPERIMENTS

Basic Level

347. Path of carbon in photosynthesis was found by using

(a) Centrifugation (b) Radio isotopes (c) Fractionation (d) Chromatography

348. How chlorophyll would appear when seen in red light

(a) Red (b) Green (c) Black (d) Colourless

349. What plant is used in an experiment commonly performed in laboratory in demonstrate evolution of oxygen in photosynthesis

(a) Sunflower (b) *Hydrilla* (c) Croton (d) Balsam

350. When a rat was placed into a closed container, it got suffocated and died but when a plant was also introduced into it, the rat survived. Who performed this experiment

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

351. Which element is left when chlorophyll is burnt

(a) Iron (b) Manganese (c) Magnesium (d) Molybdenum

352. The path of CO_2 in the dark reaction of photosynthesis was successfully traced by the use of the following or The dark reaction is traced by

(a) O_2^{18} (b) $C^{14}O_2$ (c) P^{36} (d) X-rays

353. Moll's experiment shows

(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

354. Algae used by Calvin and associates for photosynthetic research is

(a) *Chlorella* (b) *Chlamydomonas* (c) *Volvox* (d) All of these

355. 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 of these

356. McAlister and Mayer have studied the Warburg's effect on

(a) Pea (b) *Arachis* (c) Soyabean (d) All of these

357. What will be the effect on photosynthesis, if boiled water is used in one of its experiment

(a) Process will be rapid (b)Process will be low

(c) No process will take place (d) None of these

358. Warburg studied his effect on

(a) *Chlamydomonas* (b) *Chlorella* (c) *Volvox* (d) All of these

359. Which of the following technique was used by Calvin in determining carbon pathway

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

360. In an experiment on O_2 evolution by photosynthesising *Hydrilla* plant, a pinch of sodium bicarbonate is added to water. The rate of photosynthesis or O_2 evolution will

(a) Increase (b) Decrease (c) Stop (d) Not be affected

361. CO_2 is necessary for photosynthesis. The chemical used to remove this gas most effectively from entering a control apparatus is

(a)Potassium hydroxide solution (b) Calcium oxide

(c) Sodium carbonate (d) Distilled water

362. Starch is detected in food by its

(a) White appearance (b) Blue reaction with iodine solution

(c) Presence as an energy store (d) Granular from even if cooked

363. *Hydrilla* is used for demonstrating photosynthesis because it shows

(a) Little respiration (b) Little transpiration

(c) Rapid photosynthesis

(d) Evolution of O_2 bubbles which can be collected over water

364. When a potato tuber is exposed to light it develops

(a) Anthocyanin (b) Chloroplast (c) Chromoplast (d) Leucoplast

Advance Level

365. 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

(a) A plant (b) B plant (c) Both (a) and (b) (d) First (a) and then (b)

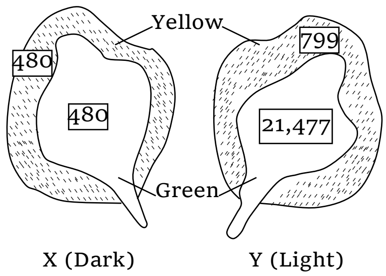
366. If half of the leaves of a plant are removed, the rate of photosynthesis would be

(a) More and the photosynthetic yield is also more (b)More but the photosynthetic yield is less

(c) Less and the photosynthetic yield is also less (d)Less but the photosynthetic yield is more

367. Variegated leaves of a plant were supplied with radioactive carbon dioxide ($^{14}CO_2$) during an experiment. Leaf *X* was kept in the dark and leaf *Y* was kept in the light. At the end of the experiment the radioactivity in the leaves was measured and found to be as shown on the diagram below.

What is the most likely explanation for the level of radioactivity found in the yellow zone of *Y*



(a) Photosynthesis occurs but no storage of starch occurs in this zone

(b) Radioactive carbon dioxide diffuses into the leaf and accumulates here

(c) Products of photosynthesis diffuse into the yellow zone

(d) Photosynthesis proceeds slowly in the absence of chlorophyll *a* and *b*

368. Engelmann's experiment with *Spirogyra* demonstrated that

(a) The full spectrum of sunlight is needed for photosynthesis

(b) Only red wavelengths are effective in causing photosynthesis

(c) Only blue wavelengths are effective

(d) Both blue and red wavelengths are effective

369. Algae float in the water during day time and sink during night time because

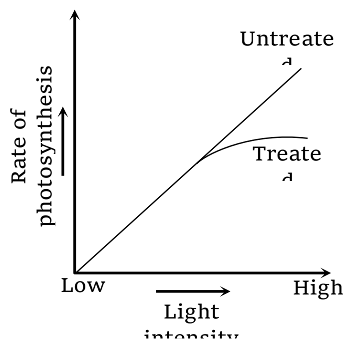
(a) They become buoyant due to consumption of food materials in respiration

(b) They loose weight at night

(c) They come up to enjoy sunshine

(d) They become buoyant in light due to accumulation of oxygen bubbles released in photosynthesis

370. The graph given below shown the effect of potassium cyanide on the rate of photosynthesis of *Chlorella* at different light intensities. Which one of the following can be deduced from the graph



(a) Potassium cyanide appears to inhibit the light (Hill) reaction

(b) Potassium cyanide appears to absorb more light at high light intensities

(c) Potassium cyanide appears to inhibit photosynthesis equally at high and low light intensities

(d) Potassium cyanide appears to have no inhibiting effect on photosynthesis at low light intensities

371. If water supply to the plant is extremely meagre to as to cause wilting of leaves, the rate of photosynthesis may

(a) Increase (b) Decrease

(c) First increase than decrease (d) First decrease than increase

372. The thylakoids are removed and kept in a culture medium containing CO_2 and H_2O. If the setup is exposed to light, hexose sugars are not formed as the end product.

The most appropriate reason for this will be that

(a) Carbon assimilation cannot take place (b)The pigments (P–700 and P–680) are not linked

(c) Enzymes are not available (d)The light trapping device is not functional

373. 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

374. Which of the following isotope of carbon was used by Calvin to trace the path of carbon in photosynthesis or The isotope of carbon used extensively for studies in photosynthesis is

(a) C^{13} (b) C^{14} (c) C^{15} (d) C^{16}

375. The experimental material that has largely been responsible for making rapid advances in research on photosynthesis is

(a)*Chlamydomonas* (b) Spinach leaf (c) *Chlorella* (d) *Hydrilla*

376. The starch is insoluble in water even than it is stored in potato in more quantity

(a) By microbes (b) Because it is manufactured in tuber

(c) Because plants use it as food

(d) Because first it come to tuber as sugar solution then it is stored as starch

377. Much of the starch is deposited in Banana fruit as it matures. Which of the following explains how the starch gets there

(a) Starch solution passes through cells from phloem to fruit

(b) Starch grains pass through cells from xylem to fruit

(c) Starch solution passes through companion cells to fruit

(d) A sugar solution passes through phloem cells to the fruit where it is changed to starch

378. Emerson found photosynthesis to increase with light flashes. Blackmann observed increase in photosynthesis with the increase in light and CO_2 till temperature became limiting. What of the following is true in light of above observation

(a) Light intensity is temperature dependent

(b) Light harvesting occurs only in the presence of CO_2

(c) Photosynthesis has two phases, light and dark

(d) One factor is limiting photosynthesis at one time

379. Match the items of column I and column II

	Column I		Column II
A	Mitchell	*p*	Steps of dark reaction of photosynthesis
B	Gibbs	*q*	Photophosphorylation
C	Arnon	*r*	Concept of free energy
D	Calvin	*s*	Chemiosmotic hypothesis
–	–	*t*	Mass flow hypothesis

(a) *A – s, B – t, C – r, D – q*
(b) *A – s, B – r, C – p, D – q*
(c) *A – r, B – s, C – p, D – q*
(d) *A – s, B – r, C – q, D – p*

C / CAM / PHOTORESPIRATION

Basic Level

380. The enzymes of dark reaction in C_4 plants are found in
(a) Bundle sheath chloroplast
(b) Mesophyll chloroplast
(c) Both (a) and (b)
(d) None of these

381. The family in which many plants are C_4 type
(a) Malvaceae
(b) Solanaceae
(c) Cruciferae
(d) Graminae

382. Which of the chloroplast does not contain grana
(a) Pea leaf
(b) Hydrophytic stem
(c) Bundle sheath of sugarcane leaf
(d) Mesophyll of grasses

383. Conversion of oxaloacetic acid into malic acid is
(a) Oxidation
(b) Reduction
(c) Carboxylation
(d) Hydroxylation

384. Which of the following enzyme is responsible for the conversion of oxaloacetic acid into malic acid
(a) PEP oxidase
(b) PEP reductase
(c) PEP dismutase
(d) Malate dehydrogenase

385. Which of the following is required for transformation of oxaloacetic acid into malic acid
(a) NADP
(b) $NADPH_2$
(c) Both (a) and (b)
(d) None of these

386. Number of carboxylation in C_4 cycle is/are
(a) 1
(b) 2
(c) 5
(d) 3

387. In Hatch and Slack pathway

(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

388. Which one statement is not true of the C_4 pathway

(a) Overcomes loss due to photorespiration (b) The CO_2 acceptor is a C_3 compound

(c) Inhibited by high CO_2 concentration

(d) It requires more energy than the C_3 pathways for production of glucose

389. In photorespiration glycolate is converted to CO_2 and serine in

(a) Chloroplasts (b) Peroxisomes (c) Vacuoles (d) Mitochondria

390. Which of the following is not a C_4 plant

(a) Sugarcane (b) Maize (c) Sorghum (d) Wheat

391. In sugarcane plant $^{14}CO_2$ is fixed in malic acid, in which the enzyme that fixes CO_2 is

(a) Fructose phosphatase (b) Ribulose biphosphate carboxylase

(c) Phosphoenol pyruvic acid carboxylase (d) Ribulose phosphate kinase

392. The first reaction in photorespiration is

(a) Carboxylation (b) Decarboxylation (c) Oxygenation (d) Phosphorylation

393. Which of the following cells of C_4 plants are prominently loaded with starch

(a) Epidermal cells (b) Mesophyll cells (c) Bundle sheath cells (d) All of these

394. Which one of the following is C_4 plant

(a) *Spirogyra* (b) *Pinus* (c) *Sorghum* (d) *Funaria*

395. Agranal chloroplasts occur in certain

(a) Succulents (b) C_4 plants (c) Hydrophytes (d) C_3 plants

396. Dimorphism of chloroplast is found in

(a) C_4 plants (b) C_3 plants (c) CAM plants (d) All of these

397. Kranz type of anatomy is found in

(a) C_2 plants (b) C_3 plants (c) C_4 plants (d) CAM plants

398. Which of the following process shows light deacidification and night acidification

(a) CAM cycle (b) C_3 cycle (c) C_4 cycle (d) All of these

399. Which of the following is a CAM plant

(a) Maize (b) Sugarcane (c) Agave (d) Mango

400. In which of the following there is a loss of energy

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

401. C_4 plants are found among

(a) Gramineae only (b) Monocots only

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

402. In C_4 plants, CO_2 combine with PEP in presence of

(a) PEP carboxylase (b) RuBP carboxylase (c) RuBP oxygenase (d) Hydrogenase

403. Which of the following anatomical features characterize a C_4 plant

(a) Chloroplast packed bundle sheath cells (b) Small-sized stomatal pores

(c) More compact mesophyll with reduced intercellular spaces (d) All of these

404. How many types of photosynthetic cells occur in C_4 plant

(a) One type (b) Two types (c) Four types (d) Eight types

405. Which one of the following is wrong in relation to photorespiration

(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

406. In CAM cycle, during formation of malic acid, stomata remains

(a) Open (b) Closed (c) Semiopen (d) Always closed

407. CAM photosynthesis occurs in plants with

(a) Thin green leaves with reticulate venation (b) Thin green leaves with parallel venation

(c) Fleshy green leaves (d) Thin coloured leaves

408. C_4 plants are adapted to

(a) Hot and dry climate (b) Temperate climate

(c) Cold and dry climate (d) Hot and humid climate

409. Which of the following is CO_2 acceptor in C_4 plants

(a) Phosphoenol pyruvate (PEP) (b) Ribulose 1, 5 diphosphate (RuDP)

(c) Oxaloacetic acid (OAA) (d) Phosphoglyceric acid (PGA)

410. C_4 photosynthesis does not occur in

(a) *Zea mays* (b) *Saccharum munja*

(c) *Saccharum officinarum* (d) *Euphorbia splendens*

411. C_4 plants are also known as

(a) Hatch and Slack type (b)Calvin type

(c) Calvin and Bassham type (d) Emerson type

412. In C_4 plants, Calvin cycle occurs in

(a) Stroma of bundle sheath chloroplast (b) Mesophyll chloroplast

(c) Grana of bundle sheath chloroplast

(d) Does not occur as CO_2 is fixed mainly by PEP and no CO_2 is left for Calvin cycle

413. In C_4 pathway or C_4 photosynthesis carbon dioxide fixation occurs in chloroplast of

(a) Palisade tissue (b) Spongy mesophyll (c) Bundle sheath (d) Guard cells

414. The first product of CO_2 fixation in Hatch and Slack (C_4) cycle in plants is

(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

415. The C_4 plants are different from C_3 plants with reference to the

(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

416. The energy wastage occurs during

(a) Dark respiration (b) Photosynthesis (c) Glycolysis (d) Photorespiration

417. Which one is a C_4 plant]

(a) Papaya (b) Pea (c) Potato (d) Maize

418. Which of the plants can show CAM cycle

(a) Members of graminae (b) Members of cactaceae

(c) Members of chenopodiaceae (d) All of these

419. Which pair is wrong

(a) C_3 – Maize (b) Calvin cycle $\rightarrow$ PGA

(c) Hatch and Slack cycle $\rightarrow$ OAA (d) C_4 – Kranz anatomy

420. C_4 plants have higher net photosynthetic rate as they have

(a) No photorespiration (b) PEP as CO_2 acceptor

(c) Kranz anatomy (d) Photosynthesis even at low light intensity

421. Photorespiration is characteristic of

(a) C_3 plants (b) C_4 plants (c) CAM plants (d) All of these

422. In *Amaranthus*, the first CO_2 acceptor is

(a) Pyruvate (b) Phosphenol pyruvate

(c) Ribulose phosphate (d) Ribulose biphosphate

423. C_4 plants require

(a) Lesser CO_2 (b) Lesser salts (c) Lesser water (d) Lesser light

424. Photorespiration occurs in

(a) Ribosomes (b) Mitochondria (c) Peroxisomes (d) Lysosomes

425. Organelles involved in photorespiration are

(a)Mitochondria, chloroplasts and ribosomes

(b)Mitochondria, peroxisomes and chloroplasts

(c) Mitochondria, nucleus and ribosomes

(d) Mitochondria, peroxisomes and glyoxysomes

426. C_4 and C_3 pathways of CAM plants are separated by

(a) Bundle sheath (b) Mesophyll and bundle sheath cells

(c) Mesophyll and bundle sheath chloroplasts (d) Time

427. PEPco is associated with

(a) C_3 plants (b) CAM plants (c) C_4 plants (d) Both (b) and (c)

428. In succulent xerophytes, there is accumulation of malic acid in night, this path of CO_2 metabolism is called

(a) Beta carboxylation (b) Hatch and Slack cycle

(c) Crassulacean acid metabolism (d) Calvin cycle

429. In C_4 – plants, photosystem II is absent in chloroplasts of

(a) Mesophyll cells (b) Bundle sheath cells

(c) Palisade cells (d) Spongy cells

430. The carbon dioxide acceptor in CAM plants is

(a) Malic acid (b) Oxalo-acetic acid (c) Pyruvic acid (d) Phosphoenol pyruvic acid

431. The first stable product in CAM/C_4 plants is

(a) Starch (b) Oxalo-acetic acid (c) Sugar (d) Malic acid

432. The co-operative photosynthesis is found in

(a) C_4 – plants (b) C_3 – plants (c) C_2 – plants (d) Succulents

433. Glycolate accumulates in chloroplasts when there is

(a) High CO_2 (b)Bright light (c) Low temperature (d) Low CO_2

434. The substrate for photorespiration is

(a) Phosphoglyceric acid (b)Glycolate (c) Serine (d) Glycine

Advance Level

435. 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

436. Which of the following is essential for the normal growth of C_4 plants

(a) Silicon (100m) (b) Vanadium (100μm) (c) Sodium (100m) (d) Barium (100m)

437. 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 of these

438. 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

439. Which of the following crop plant is very efficient convertor of solar energy and whose net productive value ranges from 2kg to 4kg/m^2 or even higher

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

440. Tropical plant like sugarcane show high efficiency of CO_2 fixation because of

(a) Calvin cycle (b) Hatch and Slack cycle

(c)EMP pathway (d) TCA cycle

441. In C_4 plants mesophyll cells are connected with bundle sheath cells with the help of

(a) Cytoplasmic connections (b) Special connecting tissues

(c) Plasmodesmata (d) Connection is not essential

***

ANSWER

ASSIGNMENT (BASIC & ADVANCE LEVEL)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
a	a	b	c	a	d	d	d	b	b	d	b	b	a	c	b	c	a	c	a
21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
b	d	c	a	c	c	b	c	d	a	a	d	d	a	d	d	a	b	c	a
41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
b	b	a	a	a	c	c	d	c	b	b	b	b	b	b	c	c	c	b	b
61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
c	b	d	c	d	c	b	d	d	b	c	d	b	a	d	c	a	a	c	a
81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
c	d	d	b	c	c	c	a	d	a	b	a	b	a	a	b	b	a	c	d
101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
a	a	a	a	a	d	b	b	d	a	b	a	b	a	a	d	d	b	c	b
121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140
c	a	b	d	d	b	c	c	d	d	c	b	a	d	d	c	b	b	d	c
141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160
b	c	c	a	d	d	a	d	b	b	c	a	c	c	b	a	c	a	c	d
161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180
b	a	d	b	a	d	c	b	b	c	d	b	b	b	a	d	c	c	c	d
181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200
c	a	c	c	a	c	b	a	a	b	a	b	a	c	b	a	b	b	b	b
201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220
b	b	d	c	c	a	b	c	b	d	b	a	c	a	a	d	a	a	a	a
221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240
a	a	b	a	a	a	b	c	d	c	c	b	b	b	d	b	c	d	a	b
241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260
a	c	a	a	b	a	a	c	b	d	d	c	c	d	b	d	b	c	b	b
261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280
b	c	a	c	b	c	a	d	d	b	b	a	b	b	a	b	b	b	a	d
281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300
b	b	c	c	a	d	c	b	c	a	b	b	a	b	c	b	c	b	b	a

301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320
a	c	a	b	b	a	d	a	b	c	c	a	d	b	b	a	d	c	d	c
321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340
c	b	a	c	b	c	a	b	c	d	c	a	b	d	a	a	c	d	b	d
341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360
c	a	b	d	a	b	b	c	b	b	c	b	c	a	d	c	c	b	a	a
361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380
a	b	d	a	a	b	c	d	d	d	b	c	c	b	c	d	d	c	d	a
381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400
d	c	b	d	b	b	b	a	d	d	c	c	c	c	b	a	c	a	c	b
401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420
d	a	d	b	d	a	c	a	a	d	a	a	b	d	a	d	d	b	a	a
421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440
a	b	a	c	b	d	d	c	b	d	d	a	d	b	c	c	c	c	a	b
441																			
c																			

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