**PHOTOSYNTHESIS**

All animals present on earth are heterotrophic in nature. They cannot manufacture their food and therefore directly or indirectly depend on plants. Plants on the other hand are autotrophic because of the presence of chloroplast in their cells. By absorbing solar radiation with the help of chlorophyll and carbon dioxide and water from atmosphere and soil, plants synthesise various organic food substances. This process is called photosynthesis.

**Development of the knowledge of photosynthesis:** Several experiments were performedto understand photosynthesis:

1. **Joseph Priestley (1733-1804)** Priestleyreported in 1770 that air plays an important role in the growth of plants. Priestley discovered oxygen in 1774.
2. **John Igenhousz 1730-1799**Through his experiments, he proved that presence of Sunlight was essential for plants while purifying the air.
3. **Antony Lavoisier** in 1785 proved that during photosynthesis plants absorb carbon dioxide and release oxygen.
4. **J. Robert Mayer** in 1845 reported that during photosynthesis plants convert solar energy into chemical energy which is stored in the form of organic compounds.
5. **T.W.Engelmann (1843-1909)** He used a Prism to break sunlight into its spectrum components which were focussed on a filament of *Cladophora*(an alga) and placed in an aqueous suspension containing aerobic bacteria. He thus defined the action spectrum of photosynthesis which was observed to match with the absorption spectra of chlorophyll.
6. **C.B. Van Niel (1897-1985)** He reported that photosynthesis is a light dependent process in which hydrogen obtained from oxidation of compounds is used in reducing carbon dioxide to obtain carbohydrates. Green plants use water as hydrogen donor.Water is oxidised to produce oxygen. Some organisms do not produce oxygen during photosynthesis. This is because these organisms (Green and Purple sulphur bacteria) use H**2**S in place of water as hydrogen donor. Due to which sulphur is released in place of oxygen. From these experiments Van Niel**,** proved that oxygen evolved during photosynthesis comes from water and not from carbon dioxide as was thought earlier.
7. **Samuel Ruben and Martin D. Kamen** in 1941 using heavy isotope of oxygen (O**18**) proved that oxygen in photosynthesis comes from water.

**Site of photosynthesis**Though the process of photosynthesis is mainly performed by green Leaves but it occurs in all other green parts of the plant. Leaves contain mesophyll cells which contain the green plastid chloroplast. Mostly chloroplasts are located in the peripheral cytoplasm in order to utilise maximum amount of incoming solar radiation. Chloroplast is a double membrane bound structure. Internally it contains a liquid called stroma or matrix. Besides this, it also contains an internal membrane system which forms structures like granna and stroma lamellae or frets. The membrane system absorbs solar energy and produces ATP and NADPH**2**through a process which is called photochemical reaction. It occurs in the presence of sunlight. In the stroma enzymatic reactions take place in which sugars are synthesized from carbon dioxide which later gets converted into starch. This reaction depends on the products of light reaction that is ATP andNADPH**2**. As this phase of photosynthesis is independent of light it was earlier called dark reaction though due to the confusion created by this name it is now called carbon reactions.

**Nature of light**The energy of Sunlight is called solar energy.According to electromagnetic wave theory given by JC Maxwell (1860) solar radiations are composed of photon (energy packets) which travel in the form of waves.The distance between crests of two waves is called the wavelength and is represented by Lambda. Light contains different wavelengths. There is inverse relationship between wavelength and energy. Higher wavelength have lower energy where as lower wavelength have higher energy. Different colours of spectrum have different wavelength.While violethas the lowest wavelength whereas red has the maximum wavelength. Red is followed by infrared rays, whereas violet is preceded by ultraviolet rays.

**Photosynthetic pigments** Plants absorb only certain wavelengths of incoming solar radiation. The remaining wavelengths are reflected back. The pigments which absorbs the solar radiations are called photosynthetic pigments such as chlorophyll a and b and carotenoids etc. These pigments are present in the membranes of grana and stroma thylakoids and absorb mainly blue, violet, red and orange wavelengths. Leaves reflect back green wavelength and therefore apear green in colour. Different pigments absorb different wavelengths of light for example chlorophyll a absorbs blue, violet or red light whereas chlorophyll b mainly absorbs blue light. Chloroplast also contains yellow, orange colour pigments called carotenoids which absorb bluegreen light.As chlorophyll a directly participate in photochemical reaction it is called primary photosynthetic pigment. Other pigments such as chlorophyll b,c,d,e and phycobilins are called accessory or secondary pigments.

**Mechanism of photosynthesis**Photosynthesis is a complex process in which radiation energy of sun is converted into chemical bond energy. It involves two phases:

1. Photochemical phase
2. Light independent chemical phase or black man reaction
3. **Photochemical phase**This phase involves water absorption, photolysis of water, oxygen evolution and synthesis of ATP and NADPH**2**. The process occurs in the presence of sunlight and involve several complexes. The pigments form two pigment systems or photosystems called photosystem I (PS I) and photosystem II (PS II).The light harvesting Complex of each photosystem is composed of several pigment molecules. Each photosystem contains all the pigments such as chlorophyll a,b,c, carotenoidsetc.

**Pigment system I(PSI):** It is also called photosystem I in PS I. Chlorophyll a 700 acts as the reaction Centre. It absorbs light of wavelength 700 mµ (millimicron).It is therefore called P700 or chlorophyll a 700.

**Pigment system II or photosystem II or PS II:** In PS II, chlorophyll a 680 acts as the reaction centre. It absorbs light of wavelength 680 mµ and therefore the reaction Centre is called P680.

**Working mechanism of PSI and PSII:**The chlorophyll a680 present in the reaction centre of PSII absorbs solar energy, gets excited and releases an electron. The released electron moves away from the nucleus and is received by an electron acceptor of electron transport system. The electron transport system contains cytochromes and other electron Carriers. The movement of electrons is downstream of redox potential of electron Carriers. Moving alone various electron Carriers the electrons are donated to photosystem I. The reaction centre of PSI also absorbs red light of wavelength 700 mµ. The electron released from a PS I in excited state is received by electron acceptor having higher redox potential. The electrons again move downstream according to their redox potential. This time the electron is transferred toNAD**+**which gets reduced to NADPH**2**. Thus the transfer of electrons starts from PS II passes through various electron carriers and then to PS I and finally to NAD**+** which gets converted into NADPH**2**.

When both the photosystems, electron carriers and NAD**+** are plotted on graph based on their redox potential and the movement of electrons is recorded then a Z shaped structure appears. This is therefore called the Z scheme of movement of electrons. Z scheme was described by Robin Hill and fay Bendall(1960).

**Cyclic and non-cyclic photophosphorylation:** organisms have the potential to store energy in high energy bonds of compounds such as ATP. The process of formation of ATP in mitochondria and chloroplast is called phosphorylation. When ATP formation occurs in the presence of Sunlight it is called photophosphorylation. Photophosphorylation is of two type non-cyclic and cyclic.

 Non-cyclic photophosphorylation operates by the involvement of both PSI and PSII. External source of electron in the form of water is required.It is non cyclic. It requires photolysis of water as a result of which hydrogen ions are produced and oxygen is evolved. ATP and NADPH**2** are produced.It is responsible for production of reducing power (NADPH**2**). It occurs in grana thylakoid.

 Cyclic photophosphorylation operates independently by PSI only.It does not require external source of electron.Electron movement is cyclic. It does not require photolysis of water. In this ATP is produced.Except some bacteria and C**4** plants it does not help in photosynthesis. Cyclic photophosphorylation usually occurs in stroma thylakoid.

**Chemiosmotic hypothesis:**How is ATP produced in chloroplast ?The process can be better explained with the help ofChemiosmotic hypothesis. As in respiration, in photosynthesis also ATP synthesis occurs due to proton gradient developed across a membrane. Here the membrane are those of thylakoids. The difference with respiration is that in photosynthesis the protons are concentrated in the lumen or channel of thylakoid whereas in respiration the protons are concentrated in the intermembrane space of mitochondria. Proton gradient across thylakoid membrane develops due to several reasons.First, due to the photolysis of water on the inner side of the thylakoid membrane and therefore hydrogen or protons are concentrated on the inner side. As the electron travels to the photosystem the protons move toward the lumen side. NADP reductase enzyme is present towards the stroma side. For getting reducedNAD**+** requires proton besides electron from PSI.NADPH**2** and ATP produced as a result of electron transport are utilised in stroma for the reduction of carbon dioxide into carbohydrates.

1. **Biosynthetic phase or blackman reaction or chemical dark reaction or light independent reaction of photosynthetic or carbon reduction cycle**

The different products of light phase are ATP, NADPH**2** and oxygen. Out of these, oxygen diffuses out of the chloroplast whereas ATP and NADPH**2**are utilised in dark phase of photosynthesis. It is also called the biosynthetic phase. This process is independent of light but is dependent on the products of light phase that is ATP and NADPH**2** and also carbon dioxide and water. It occurs in stroma of chloroplast. Melvin Calvin used radioactive carbon C**14** in carbon dioxide and provided it to some algae. From these experiments he reported that the first product of CO**2** fixation was a three carbon compound phosphoglyceric acid (PGA).

 Two main methods of carbon dioxide assimilation are known. Plants in which the first stable product of carbon dioxide fixation is a three carbon compound,phosphoglyceric acid, the cycle is called C**3** cycle. Plants in which the first stable product is a four carbon compound oxaloacetic acid it is called the C**4** pathway.

**Calvin cycle** M. Calvin, A.Benson and their associates discovered the complete pathway of carbon fixation in *Chlorella,* a green algae using radioactive tracer technique. They reported that the path is circular and RuBP (Ribulosebiphosphate) is regenerated. For this, they used labelled carbon dioxide containing radioactive carbon. Calvin cycle occurs in all plants performing photosynthesis irrespective of C**3** or C**4** pathway. For understanding Calvin cycle three phases need to be described:

1. **Carboxylation-**Carbon dioxide fixation results in the synthesis of an intermediate compound which breaks up into two molecules of 3PGA. The reaction is catalyzed by the enzyme **Rubisco** (RuBP carboxylase oxygenase).
2. **Reduction-**This is the chain of reactions which lead to the formation of glucose. In this step, for the fixation of one carbon dioxide molecule two ATP molecules are required for phosphorylation and two NADPH**2**are required for reduction. For the synthesis of one Glucose molecule fixation of 6 molecule of CO**2**and 6 round of Calvin cycles are required.
3. **Regeneration**- If Calvin cycle has to occur uninterruptedly again and again then CO**2**acceptor RuBP needs to be regenerated in each cycle. For the regeneration of RuBP an ATP is required for phosphorylation.