11

PHOTOSYNTHESIS

Q What is photosynthesis ? Give a brief account of its discovery.

PHOTOSYNTHESIS

Although literary meaning of photosynthesis is 'synthesis with the help of light' ... term is usually applied to a very important vital process by which the green plants ... **organic matter** in presence of light. Photosynthesis is sometimes called as **carbon** ... **tion** and is represented by the following traditional equation.

$$6CO_2 + 6H_2O \xrightarrow[\text{Green Plant}]{\text{Light}} 6O_2 + \underset{\text{Hexose Sugar}}{C_6H_{12}O_6}$$

In recent years, this equation has more appropriately been modified as follows :

$$6CO_2 + 12H_2O \xrightarrow[\text{Green Plant}]{\text{Light}} 6O_2 + 6H_2O + \underset{\text{Hexose Sugar}}{C_6H_{12}O_6}$$

During the process of photosynthesis the light energy is converted into **chemical** ... and is stored in the organic matter which is usually the carbohydrate and along with O_2 ... the **end products** of photosynthesis. One molecule of glucose ($C_6H_{12}O_6$) for instance, ... about **686 K. Cal**. (2868 kJ) of energy. **CO_2 and H_2O** constitute the raw materials for this process.

About 90% of the total photosynthesis in the world is carried out by algae growing ... in oceans* and also in fresh water.

Significance of Photosynthesis to Mankind

- It maintains equilibrium of O_2 in the atmosphere.
- It provides food either directly as vegetables, or indirectly as meat or milk of ... which in turn are fed on plants.
- Besides providing energy in the form of food, photosynthesis has also provided ... reserves of energy to man as **fuel** such as coal, oil, peat and also wood and ...

HISTORY OF PHOTOSYNTHESIS

The history of photosynthesis dates back to about 1648 when **Van Helmont** planted ... pounds willow shoot in 200 pounds of dried soil. After 5 years of watering with rain water ...

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*This is an estimate by Rabinowitch (1951). According to more recent figures given by ... (1970) and Woodwell (1970), only one third of the total global photosynthesis can be attributed to ... marine plants willow tree weighed 169 pounds. When the soil was dried and again reweighed, it was found to have lost only 2 ounces. He suggested that the increase in the plant substances of the willow tree must have come from water alone. Prior to this and from the time of **Aristotle** the idea was prevalent that the plants feed on **humus**.

Stephan Hales (1727) pointed out that the plants obtained a part of their nutrition from the air and also suggested that sunlight may play a role in it.

Priestley (1772) showed that the plants might restore the air which has been "injured" (*i.e.*, laden with CO_2) by the burning of candles.

Ingenhousz (1779) noticed that only the green parts of the plants were able to purify the air and that too in the presence of sunlight.

Jean Senebier (1782) noted that the air-purifying activity of plants depends on the presence of fixed air (*i.e.*, CO_2) and suggested that the air (O_2) liberated by plants which are exposed to sunlight is the product of the transformation of fixed air (CO_2) by sunlight.

Nicolas Theodore de Saussure (1804) showed that the total weight of the organic matter produced and oxygen evolved by the green plants in presence of sunlight was greater than the weight of fixed air (CO_2) consumed by them during this process. He concluded that besides fixed air (CO_2) water must constitute the raw material for this process.

In 1845 **Meyer** recognised the role of light as a source of energy and thus it became possible to formulate the overall process of photosynthesis as conversion of water, CO_2 and light energy into O_2 and organic matter containing chemical energy by the green plants and which could be represented by the following equation.

$$CO_2 + H_2O \xrightarrow[\text{Green plants}]{\text{Light}} O_2 + \text{Organic Matter Containing Chemical Energy}$$

In 1864 **Julius Sachs** showed that the process of photosynthesis takes place in **chloroplasts** and results in the synthesis of starch (organic matter).

Q. Write explanatory notes on

(i) Photosynthetic apparatus.
(ii) Photosynthetic pigments and the absorption of light energy by them.
(iii) Excited states of molecules, fluorescence and phosphorescence.
(iv) Quantum requirement and quantum yield.
(v) Red drop and Emerson's enhancement effect.
(vi) Two pigment systems.
(vii) Quantasomes, and
(viii) Action spectrum.

PHOTOSYNTHETIC APPARATUS

The **chloroplasts** in green plants constitute the photosynthetic apparatus. Typically, the chloroplasts of higher plants are discoid or ellipsiodal in shape, 4–6μ in length and 1–2μ thick. The chloroplast is bounded by **two membranes** each app. 50 Å thick and consisting of **lipid bilayer** and **proteins**. (The thickness of the two membranes including the space enclosed by them is app. 300 Å) Internally the chloroplast is filled with a hydrophilic matrix called as **stroma** in which are embedded **grana**. Each granum has a diameter of 0.25–0.8μ and consists of 5-25 disk shaped **grana lamellae** placed one above the other like the stack of coins (Fig. 11.1 A). In cross section these lamellae are paired to form sac like structures and have been called as **thylakoids**. Each grana lamella or thylakoid encloses a space, the **loculus**. The ends of disk-shaped thylakoids are called as **margins** (which are fused to form sac like structure) while contiguous membranes between two thylakoids form the **partition**. Some of the grana-lamellae or thylakoids of a granum are connected with thylakoids of other grana by somewhat thinner **stroma-lamellae** or **fret membranes**. These also enclose spaces which are called as **fret-channels** (Fig. 11.1 B). Thylakoid membranes and stroma lamellae both are composed of lipid layer and proteins.

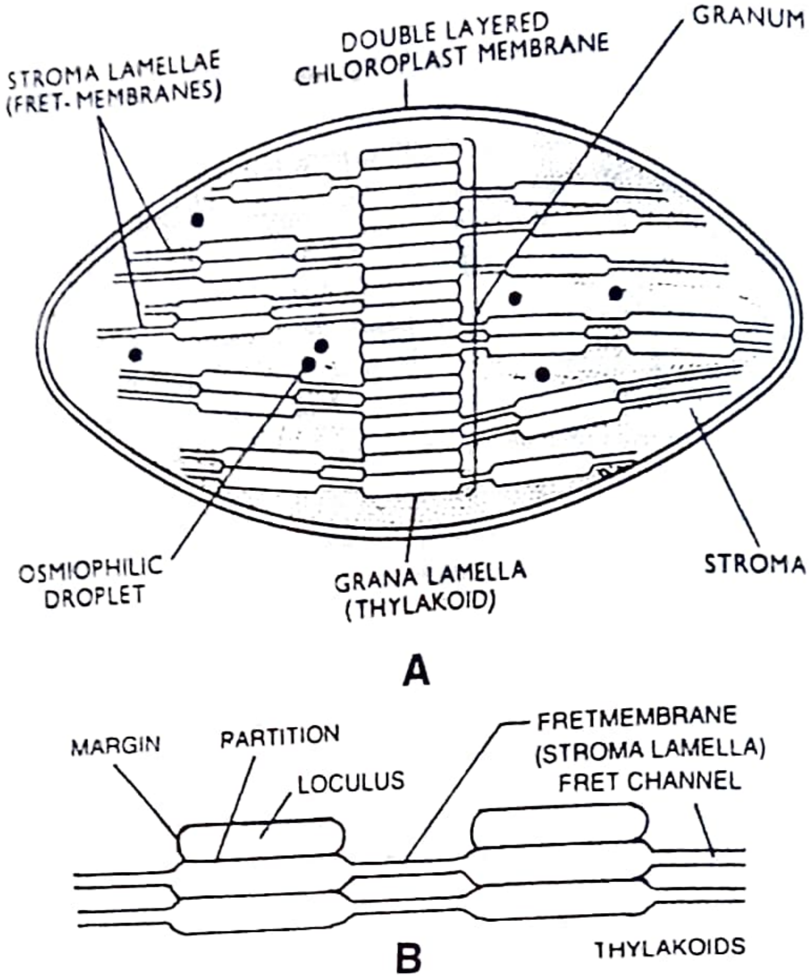


Fig. 11.1. A. Internal structure of a chloroplast.
B. Few enlarged thylakoids from two grana.

Chlorophylls and other photosynthetic pigments are found in the form of **protein pigment complexes** mainly in thylakoid membranes of grana. The latter are sites of **primary photochemical reaction**. Some of the protein-pigment complexes are also found in stroma lamellae. Dark **reaction** of photosynthesis occurs in **stroma**.

Besides necessary enzymes, some ribosomes and DNA have also been found in chloroplasts which give them (chloroplasts) a **partial genetic autonomy**.

PHOTOSYNTHETIC PIGMENTS

Photosynthetic pigments are of three types :-

(1) **Chlorophylls**, (2) **Carotenoids**, and (3) **Phycobillins**.

- Chlorophylls and carotenoids are insoluble in water and can be extracted only with organic solvents.
- Phycobillins are soluble in water.
- Carotenoids include **carotenes** and **xanthophylls**. The latter are also called as **carotenols**

- Different pigments absorb light of different wavelengths and show characteristic absorption peak *in vivo* and *in vitro*.
- They show property of fluorescence.

Distribution of Photosynthetic Pigments in Plant Kingdom

The distribution of the different types of photosynthetic pigments in plant kingdom is shown in table 11.1.

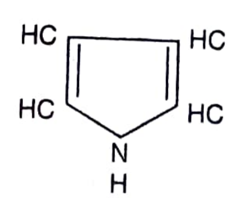
Table 11.1. Distribution of Photosynthetic Pigments in Plant Kingdom.

Pigment	Distribution in Plant Kingdom
(1) **Chlorophylls**	
Chlorophyll-a	All photosynthesizing plants except bacteria.
Chlorophyll-b	Higher plants and green algae
Chlorophyll-c	Diatoms, dinoflagellates and brown algae
Chlorophyll-d	In some red algae
Chlorophyll-e	In *Tribonema* and zoospores of *Vaucheria*
Bacteriochlorophyll-a	Purple and green bacteria
Bacteriochlorophyll-b	In a strain of purple bacterium *Rhodopseudomonas*
Bacteriochlorophyll-c, d & e (Chlorobium chlorophyll or Bacterioviridin)	Green bacteria
Bacteriochlorophyll-g	Heliobacteria
(2) **Carotenoids***	
Carotenes	Mostly in algae and higher plants
Xanthophylls (Carotenols)	Mostly in algae and higher plants
(3) **Phycobillins**	
Phycoerythrins	In blue-green and red algae
Phycocyanins	In blue-green and red algae
Allophycocyanin	In blue-green and red algae

Structure of Photosynthetic Pigments

(1) **Chlorophylls**. They are **magnesium porphyrin** compounds. The porphyrin ring consists of four **pyrrol** rings joined together by **CH** bridges. A long chain of C atoms called as **phytol** chain is attached to porphyrin ring at iv pyrrol ring.

- Chemical structures of chlorophyll-a and chlorophyll-b are well established.



PYRROL RING

*Carotenoids are also found in all photosynthetic bacteria but they are structurally different from those of algae and higher plants.

- Molecular formulae of chlorophyll-a and chlorophyll-b are $C_{55}H_{72}O_5N_4Mg$ and $C_{55}H_{70}O_6N_4Mg$ respectively.
- Molecular structure of chlorophyll-a and b are given in Fig. 11.2. Both of them consists of **Mg-Porphyrin 'head'** which is **hydrophilic** and a **phytol 'tail'** which is lipophilic. The two chlorophylls differ because in chlorophyll-b there is a -CHO group instead of a $-CH_3$ group at the 3rd C atom in II pyrrol ring.
- Chlorophyll is formed from **protochlorophyll** in light. The protochlorophyll lacks two hydrogen atoms one each at 7th and 8th C atoms in IV pyrrole ring.

$$\text{Protochlorophyll} \xrightarrow[2H]{\text{Light}} \text{Chlorophyll}$$

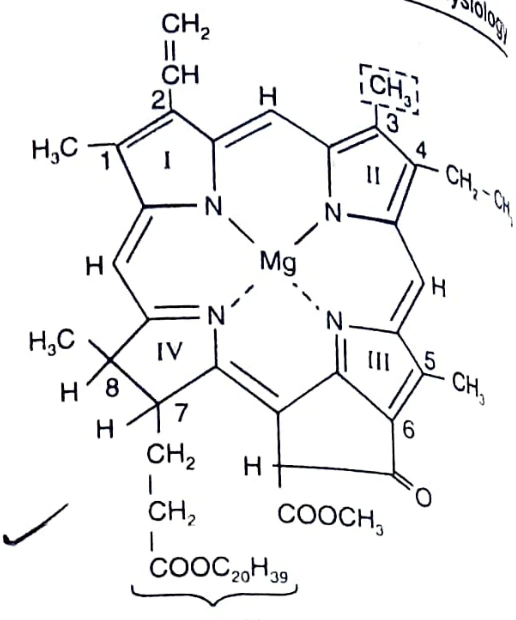


Fig. 11.2. Structural formula of chlorophyll-a. The formula for chlorophyll-b is the same except that there is-CHO group in place of $-CH_3$ group enclosed in dotted space.

(2) Carotenoids (Yellow or Orange Pigments)

(*i*) **Carotenes**

- These consist of an open chain conjugated double bond system ending on both sides with **'ionone' rings**.
- They are **hydrocarbons** with a general molecular formula $C_{40}H_{56}$.
- Different carotenes differ only in the arrangement of their molecules in space *i.e.*, they are **sterioisomers.** Structural formula of β-carotene is given in Fig. 11.3.

(*ii*) **Xanthophylls (Carotenols).** These are similar to carotenes but differ in having two **oxygen atoms** in the form of hydroxyl, carbonyl, or carboxyl groups attached to the 'ionone' rings. Accordingly, their general formula is $C_{40}H_{56}O_2$.

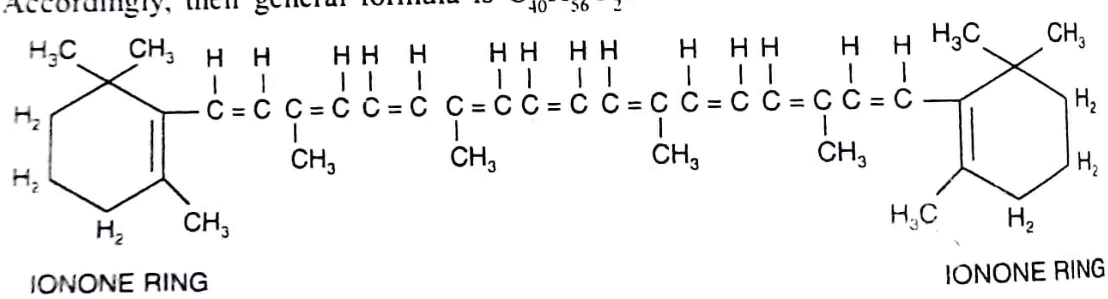


Fig. 11.3. Structural formula of β-carotene.

Apart from their role in absorption of light energy and its transfer to chlorophyll-a, the carotenoids play a very important role in preventing **photodynamic damage** within the photosynthetic apparatus. Photodynamic damage is caused by oxygen molecules in their first singlet state which is very reactive and is capable of oxidising whole range of organic compounds such as chlorophylls and thereby making them unfit (damaging) for their normal physiological functions. Carotenoids can prevent this photodynamic damage (*i*) by quenching the first excited triplet state of the chlorophyll photosynthesizer (*ii*) by quenching singlet oxygen directly and (*iii*) rarely, some of the carotenoid molecules may act as substrate for oxidation by singlet oxygen, which may have left in (*i*) and (*ii*).

(3) **Phycobillins** (Red and Blue Pigments).

These consist of an **open** conjuagted system of four pyrrol rings and lack Mg and the phytol chain. The structure of the red pigment **phycoerythrobillin** is given in Fig. 11.4.

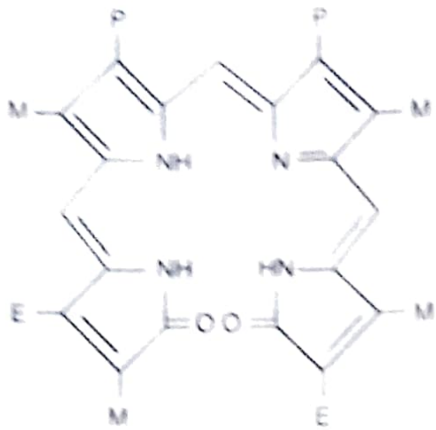


Fig 11.4. Structure of phycoerythrobilin (M methyl, E ethyl, P propionyl group)

Location of Photosynthetic Pigments in Chloroplasts

According to the classical unit membrane model of cell membranes, the photosynthetic pigments were thought to be located in **grana** portions of the chloroplasts in higher plants. A number of molecular models of the chloroplasts showing the arrangement of pigment molecules were given by different workers from time to time and it was usually held that chlorophyll molecules formed a **monomolecular layer** between the **alternative** protein and the lipid layers in grana lamellae (thylakoids)). The **hydrophillic 'heads'** of the chlorophyll molecules remain embedded in the protein layer while the **lipophilic** phytol **'tails'** in the lipid layer (Fig 11.5).

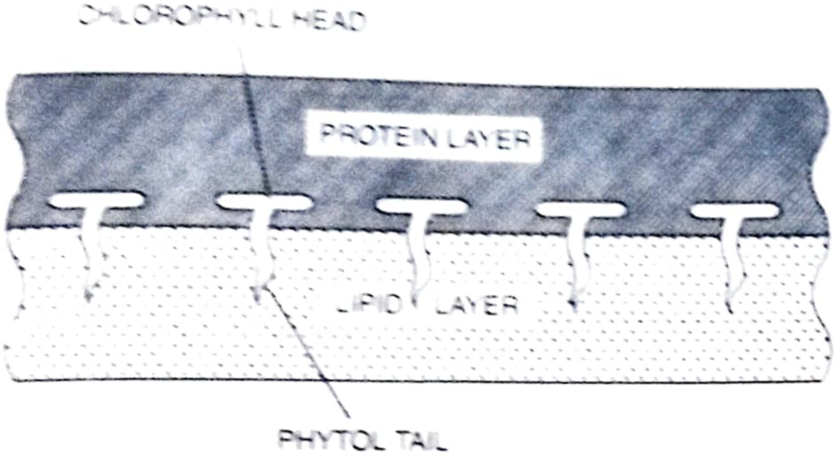


Fig 11.5. A model showing monomolecular layer of chlorophylls in between protein and lipid layers of grana lamellae. (After Rabinowitch and Govindjee).

The other pigments were thought to be present **along with the chlorophyll molecules**. **Weier and Benson** (1966, 1967) had also included chlorophyll molecules in the **fret membranes** (stroma lamellae) in their model of the chloroplasts.

- In recent years the Fluid Mosaic Model of cell membranes has been widely recognised. Accordingly, the perception regarding the location of photosynthetic pigments in lamellar membranes within the chloroplasts has also been changed. It is now widely accepted that the photosynthetic pigments occur as **protein-pigment complexes** as parts of photosytems (pigment systems) I and II which are dispersed in the lipid bilayer of thylakoid membranes of grana. They may also be present in stroma lamellae (Fig. 11.6). (For details of Fluid Mosaic Model of cell-membranes, see Chapter 1).

Absorption and Utilisation of Light Energy by Photosynthetic Pigments.

- Chief source of light energy for photosynthesis is **sun**.
- The earth receives only **about 40% (or about 5 x 10^{20}K.cal.)** of the total solar energy. The rest is either absorbed by the atmosphere or is scattered into space.
- All the incident light energy falling on green parts of the plants is not absorbed and utilized by pigments. Some of the incident light is **reflected**, some is **transmitted** through them while only a small portion is absorbed by the pigments.