DISCOVERY OF PHOTOSYNTHESIS

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PHOTOSYNTHESIS — HISTORICAL BACKGROUND AND IT'S SIGNIFICANCE :

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Photosynthesis is an energy transduction reaction, in which energy of sunlight is transduced to chemical energy. The ultimate product of photosynthesis is the synthesis of carbohydrate through a complex series of chemical reactions and the evolution of oxygen by the chlorophyll containing plant cells utilizing CO_2 and H_2O as raw materials.

The overall reaction of photosynthesis of green plants as proposed by van Niel (1941) is —

$$CO_2 + 4H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} (CH_2O) + 3H_2O + O_2$$

which is the sum of three individual reactions,

(i) $4H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} 4(OH) + 4H$

(ii) $4H + CO_2 \longrightarrow (CH_2O) + H_2O$

(iii) $4(OH) \longrightarrow 2H_2O + O_2$

In this process O_2 comes out from water and CO_2 is reduced to carbohydrate. The reducing factor $NADPH + H^+$ and energy rich ATP are formed during the light reaction and CO_2 fixed in the dark reaction of photosynthesis.

The overall equation of photosynthesis is

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

Historical Background :

(1) Aristotle and his disciple Theophrastus (384-322 B.C.) considered that plants obtain their food from soil humus. This idea was not challenged for over 17 century and became famous as "Humus Theory"

② In 17th Century J.B. van Helmont rejected the ancient idea of Humus theory. He performed willow tree experiment which was grown for over 5 years. Initial weight of the tree was 2.27 kg which grew to 67.7 kg. However, the weight of soil only decreased by 57 gram. van Helmont came to the conclusion that plant must take most of their weight from water. He did not know about gases. So, his view was partially correct.

③ Marcello Malpigi (1671) in his book '<u>Anatome Plantarum Idea</u>' had indicated that the green leaves are the organs which prepare food for the plants.

③ Stephen Hales (1677-1761) was the first to report that gaseous constituents of the air and light also contribute to the building of the plant body.

④ Joseph Priestly (1772) carried out a series of experiment with a mouse, a candle and a sprig of mint under the air tight jar. He found that the air became impure if a burning candle is kept in it. The impure air did not support the life and the mouse died soon when kept inside the bell jar. However, when few mint plants were kept in the bell jar, the mouse survived because the impure air within it become pure. On basis of these experiments, he concluded that plants purify the air.

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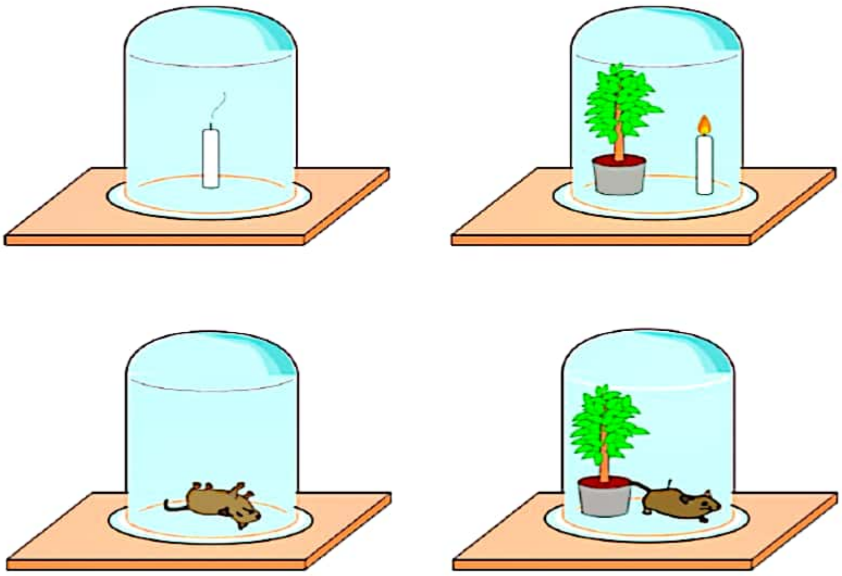


(5) Jan Ingen-Housz (1779) - wrote a book in which he described that in sunlight green leaves and stalks give out dephlogisticated air (air rich in O_2) and in dark green parts give out phlogisticated air (air rich in CO_2) and make the air impure.

(6) Jean Senebier (1782) - discovered that under certain circumstances green plants utilize CO_2.

Both the above experiments were the landmark in the discovery of photosynthesis

(7) Nicholas T. de Saussure observed that plants could not survive in the absence of both O_2 & CO_2. He also tried to prove that the vol. of CO_2 consumed was equal to the vol. of O_2 liberated. He also observed that water is used in photosynthesis. On the basis of experiments, he also concluded that O_2 liberated in the process is derived from CO_2.

(8) P.J. Pelletier and J.B. Caventou (1818) isolated and named the green coloured substance in the leaves as Chlorophyll.

(9) Julius Robert Meyer (1845) pointed out the conversion of solar energy into a useful form of chemical energy.

(10) Julius Von Sachs (1862) and his students demonstrated that starch was the end product of photosynthesis. They were credited for laying the foundation of modern views on photosynthesis.

(11) F.F. Blackman (1905), a British plant physiologist, made some remarkable discovery. He observed that the process of photosynthesis has two steps — a photochemical reaction which proceeds only in the presence of light and a dark reaction for which light is not necessary. Besides this he also put forward the "law of limiting factor".

(12) O. Warburg (1919) - also gave the existence of two reactions of photosynthesis. In his experiments on algae <u>Chlorella vulgaris</u> and <u>Scendesmus obliques</u>, Warburg observed that photosynthetic yield per second was higher when the algae

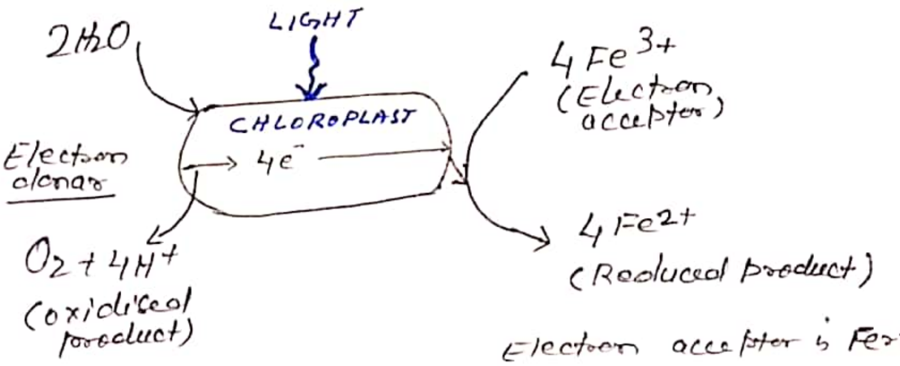
were placed in intermittent light (short periods of alternating light and dark period) than in continuous light of the same intensity.

(13) Emerson and Arnold (1932) gave the evidence of existence of two distinct photochemical processes.

Emerson & co-workers later on (1943) measured the efficiency of photosynthesis of chlorella cells and gave the concept of "red drop" and "Emerson enhancement effect"

(14) Robert Hill (1937) demonstrated that in the presence of sunlight, water and a suitable hydrogen acceptor, isolated chloroplasts release oxygen, even if CO_2 is absent.

Thus Hill's experiment proved that in photosynthesis oxygen is evolved from water and not from CO_2.



Electron acceptor is Ferricyanide which is reduced to Ferrocyanide by photolysis of water

This was an important landmark and because of this the Light reaction of photosynthesis is also known as "HILL'S Reaction."

(15) Ruben, Hassid and Kamen (1941), using radioactive technique i.e. water containing radioactive isotope of oxygen (H_2O^{18}) instead of ordinary oxygen (H_2O^{16}), also proved that the source of oxygen in photosynthesis is water.

(16) Malvin Calvin and his coworker (1954) discovered various reactions involved in the conversion of CO_2 into carbohydrate using $C^{14}O_2$. The reactions of CO_2 fixation by C3-cycle is also popularly known as "CALVIN CYCLE". He was awarded Nobel Prize for this work in 1961.

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(17) M.D. Hatch and C.R. Slack (1967) discovered a new series of reactions involved in CO_2 fixation in many tropical plants. In these plants the first stable product was a 4-carbon compound (MALATE). Hence, this new cycle is also known as C-4 cycle or Hatch and Slack pathway.

(18) Huber, Michel and Deisenhofer (1985) crystallized the photosynthetic reaction centre of Rhodobacter (bacteria) and investigated its structure using x-ray crystallography technique. They were awarded Nobel prize for this work in 1988.

(19) Bassel Kok (1970) suggested that oxygen producing complex in Photosystem-II could exist in several different transient states of oxidation, that he called 'S' states. Each 'S' state contributed to four stage water oxidizing cycle or clock.

(20) E.K. Pistorius (1993) – ~~....~~ the ~~.....~~ worked on cyanobacteria Synechococcus and explained the various components of PS-II.

(21) P.R. Chitnis (1996) – gave the structural ~~.....~~ model of PS-I.

(22) Govindjee – born on 24th Oct. 1932, an Indian-American scientist; considered a pioneer in the area of photosynthesis with primary focus on the function of the oxygen-releasing Photosystem II.
In 1960 he described the role of chl.a in PS-II.

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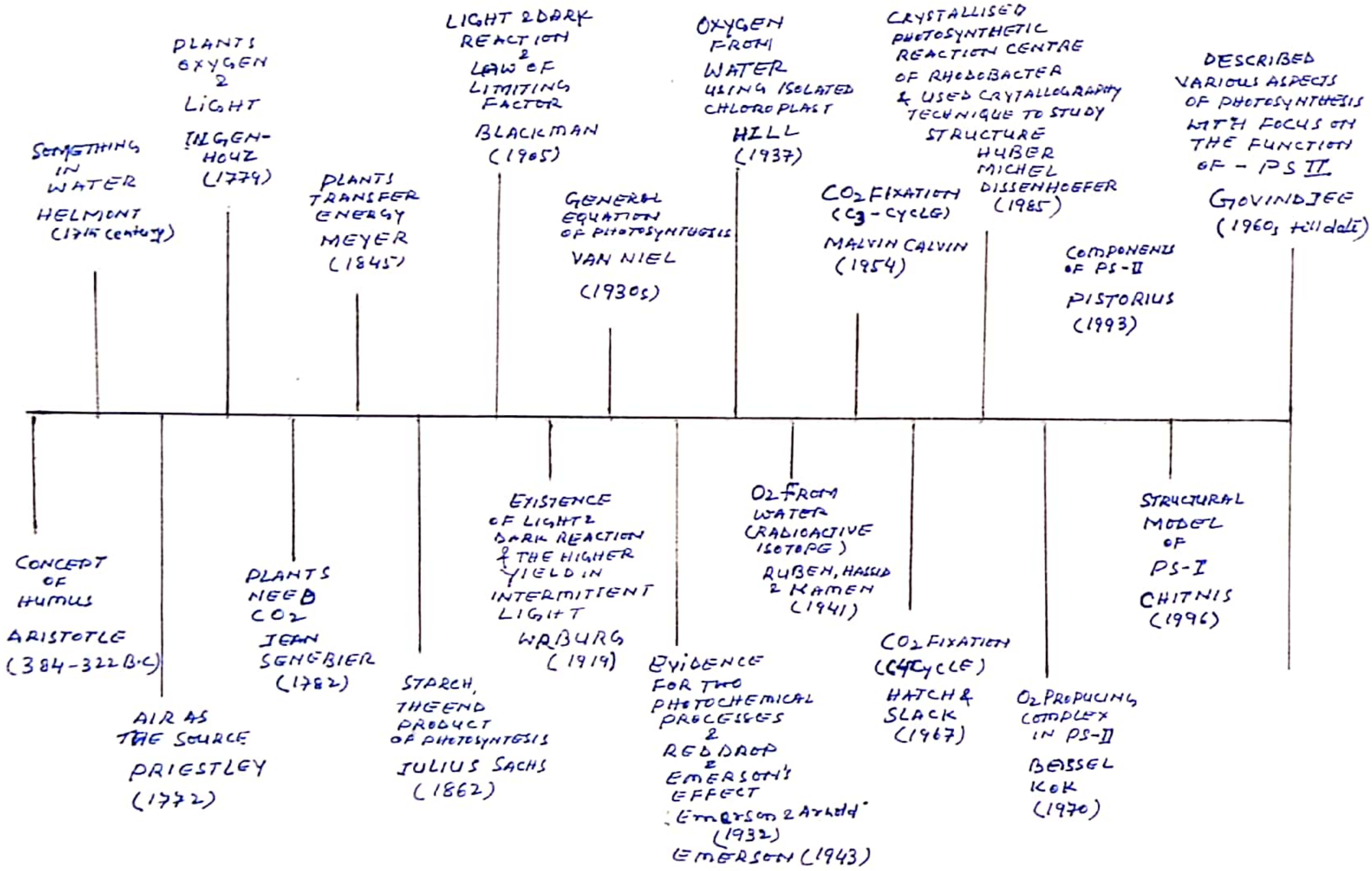
HISTORICAL BACKGROUND OF PHOTOSYNTHESIS



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SIGNIFICANCE OF PHOTOSYNTHESIS:

Photosynthesis is the single-most important physico-chemical process on which the existence of life on earth depends. It is the ability of green plants to utilise the energy of light (solar energy) to produce carbon-containing organic materials from stable inorganic matters. It is from this organic materials or carbohydrates, the countless number of other organic compounds which compose the living world are derived. The oxidation of these compounds released stored (food) energy to be utilized by organisms to carry out essential metabolic processes.

According to a rough estimate approximately 27.5×10^{10} tons of CO_2 is utilized in the process of photosynthesis anually. Thus enormous amounts of raw materials i.e. CO_2 and H_2O are transformed into carbohydrate by this process. Even though, the fact is that the energy conversion (light to chemical) efficiency is very low. The process converts only 0.1 to 1.0 of the total solar energy available on the earth's surface.

Bowen (1966) estimated the amount of CO_2 fixed anually by green plants belonging to different community level, such as Forest, Grassland, Deserts, Tundra & Ice and Fresh water as well as Ocean bodies. The productivity varies widely in different plant communities. Of the total 1.39×10^{14} kg/yr CO_2 fixed, forests have got the highest rate of CO_2 fixation (0.62×10^{14} kg/yr.), the grass land 0.25×10^{14} and ocean 0.293×10^{14}. The total land plants account 1.10×10^{14} kg/yr, thus, the forest cover alone does more than 50% of CO_2 fixation despite the fact that forest has less than 30% area of land under its cover. Of the water bodies fresh realise lakes, rivers etc account a negligible amount of CO_2 fixation i.e., 0.0002×10^{14} kg/yr, thus bulk of fixation is done by ocean.

Thus, the plants are the ultimate source of energy on which the entire other creatures depend for their survival.

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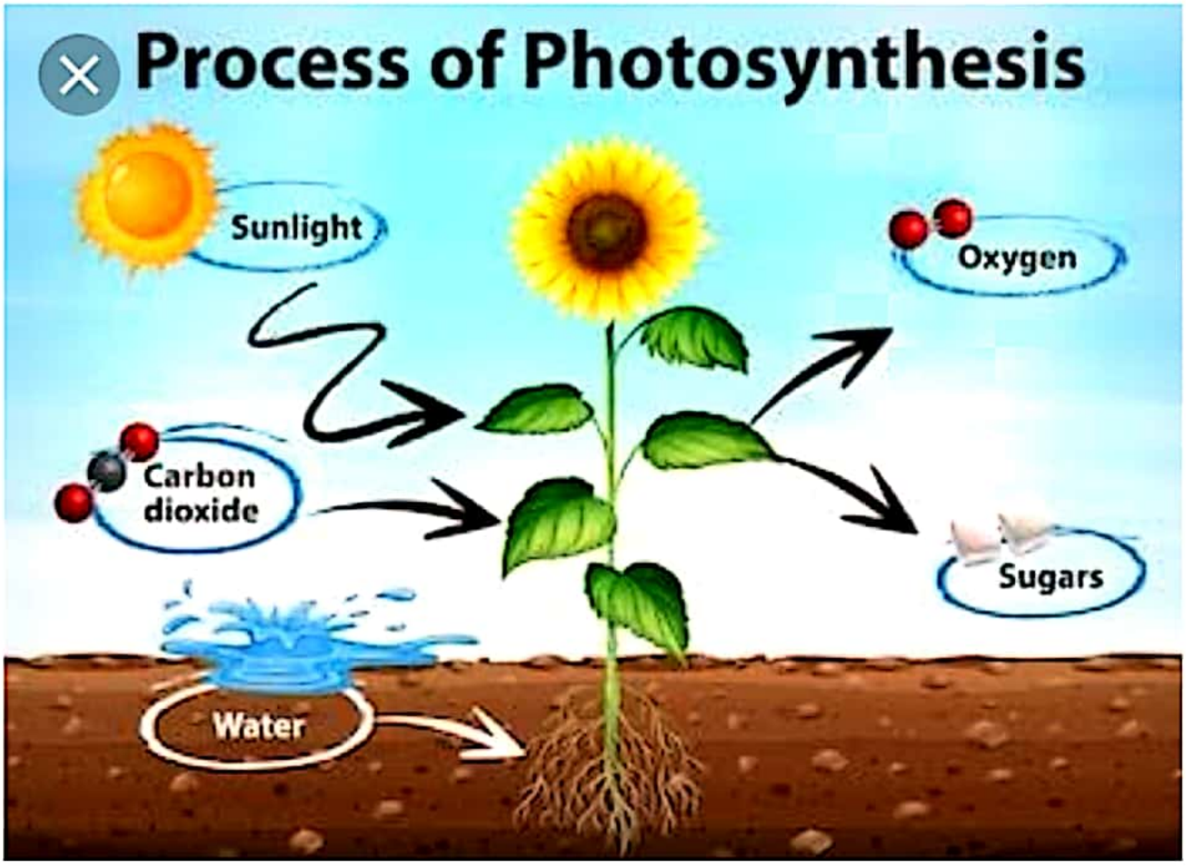

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