PHOTOSYNTHESIS IN HIGHER PLANTS

PHOTOSYNTHESIS

INTRODUCTION

The synthesis of complex organic substances (carbohydrates) by green parts of the plants in the presence of light with the help of CO_2 and H_2O is called photosynthesis. It can be shown by following equation.

$$6CO_2 + 12\,H_2O \xrightarrow[\text{sunlight}]{\text{chlorophyll}} C_6H_{12}O_6 + 6H_2O + 6O_2$$

- Photosynthesis was firstly observed in **cyanobacteria.**

Photosynthesis

i. **Physico-chemical process – Use of light energy to drive the synthesis of organic compounds.**

ii. **Redox process** – In which **water** is **oxidized** to form $\mathbf{O_2}$ while $\mathbf{CO_2}$ is **reduced** to form **sugars**. Thus it is an oxidation reduction reaction.

iii. **Endothermic –** It is accompanied by the absorption of heat.

- **Green plants carry out 'photosynthesis', all living forms on earth depend on sunlight for energy. The use of energy from sunlight by plants doing photosynthesis is the basis of life on earth.**

- **Photosynthesis is important due to two reasons:**

(i) **It is the primary source of all food on earth.**

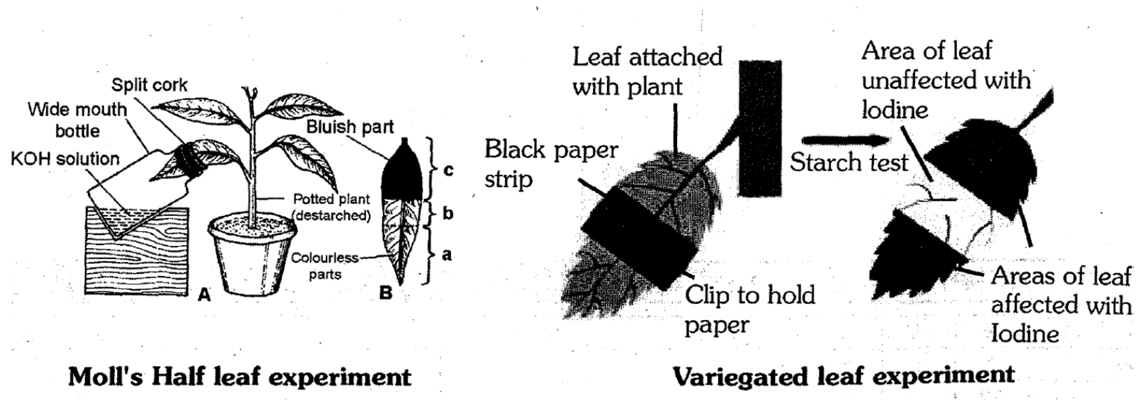
(ii) **It is also responsible for the release of oxygen into the atmosphere by green plants.**

WHAT DO WE KNOW?

Some simple experiments you may have done in the earlier classes have shown that chlorophyll (green pigment of the leaf), light and CO_2 are required for photosynthesis to occur.

You may have carried out the experiment to look for starch formation in two leaves – **a variegated leaf** or **a leaf that was partially covered with black paper, and exposed to light. On testing these leaves for the presence of starch it was clear that photosynthesis occurred only in the green parts of the leaves in the presence of light.**

Another experiment you may have carried out where a part of a leaf is enclosed in a test tube containing some KOH soaked cotton (which absorbs CO_2), while the other half is exposed to air. The setup is then placed in light for some time. On testing for the presence of starch later in the two parts of the leaf, you must have found that the exposed part of the leaf tested positive for starch while the portion that was in the tube, tested negative. This showed that CO_2 was required for photosynthesis.



Early experiments

Stephen Hales : He is credited for discovery of photosynthesis and known as father of plant physiology.

Joseph Priestly (1733-1804): He proved that green plants clean air. He proved his concept through belljars experiment.

Priestley's experiments observed that

(i) A candle burning in a closed space- a bell jar, soon gets extinguished.

(ii) Similary, a mouse would soon suffocate in a closed space.

Conclusions of his experiments – He concluded that a burning candle or an animal that breathe the air, both somehow, damage the air.

But when he placed a mint plant in the same bell jar, he found that the mouse stayed alive and the candle continued to burn.

Hypothesis of Priestley – Plants restore to the air whatever breathing animals and burning candles remove.

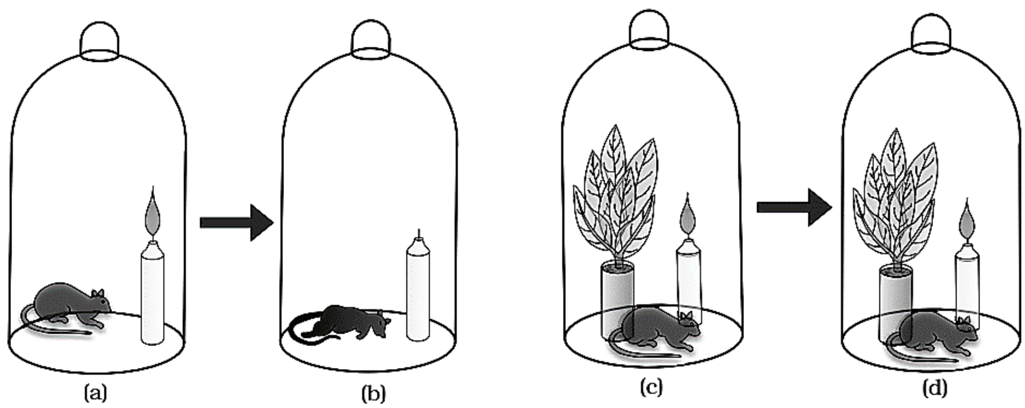


Figure: Priestley's experiment

How many different ways can you think of to light the candle without disturbing the set-up?

Using a similar setup as the one used by Priestley but by placing it once in the dark and once in the light, he showed that sunlight is essential to the plant process (photosynthesis) that somehow purifies the air fouled by burning candles or breathing animals.

In an another elegant experiment with an aquatic plant slowed that in bright sunlight small bubbles were formed around the green parts, while in the dark they did not.

Conclusion :

It is only the green parts of the plants that could release oxygen in the presence of sunlight. **Julius Von Sachs (1854) :**

He provided evidences for production of glucose when plants grow. Glucose is usually stored as starch.

Glucose - Chemically reactive and soluble

Sucrose - Chemically inactive and soluble

Starch - Chemically inactive and insoluble

His later studies showed that the green substance in plants is located in special bodies within plant cells. (Today the green colour substance is known as chlorophyll and special bodies are chlordplasts)

By the middle of nineteenth century the empirical eguation representing the total process of photosynthesis for oxygen evolving organisms was then understood as :

$$CO_2 + H_2O \xrightarrow{\text{Light}} [CH_2O] + O_2$$

where $[CH_2O]$ represented a carbohydrate (eg. Glucose, a six carbon sugar)

Cornelius Van Niel (1891-1985)

A milestone contribution to the understanding of photosynthesis was made by him. He was a microbiologist. He based upon his studies of purple and green bacteria. demonstrated that

"Photosynthesis is essentially a light dependent reaction in which hydrogen from a suitable oxidisable compound reduces carbon di-oxide to carbohydrates"

This can be expressed by :

$$2H_2A + CO_2 \xrightarrow{\text{Light}} 2A + CH_2O + H_2O$$

- In green plants and BGA. H_2O is the hydrogen donor and is oxidised to O_2.
- In purple and green sulphur bacteria H_2S is the hydrogen donor and is oxidised to sulphur or sulphate depending on the organism.
  "He inferred that the O_2 evolved by the green plant comes from H_2O. not from CO_2"

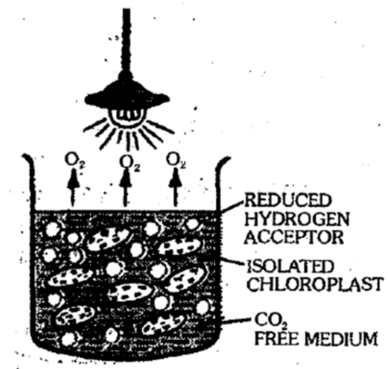
Robert Hill and Bendall :

They are credited for :

- Detailed study of light reaction and proposed Z scheme.

R. Hill:-

Detailed study of light reaction in isolated chloroplast of Stellaria plant. He illuminated the isolated chloroplasts of Stellaria media in the presence of hydrogen acceptors (ferricyanides) in the absence of carbon dioxide. The chloroplasts evolved oxygen



$$2A + 2H_2O \xrightarrow[\text{Hill reagent}]{\text{Sunlight}} 2AH_2 + O_2$$

A = Hydrogen acceptor (Hill reagent)

Hill reagent

- Natural
  - Eg. NADP
- Artificial
  - Eg. Potassium ferricyanide, Benzoquinone, Benzoquinone, chromate and DCPIP etc.

DCPIP (Dichlorophenol indophenols) is a blue colour dye, which become colourless on reduction.

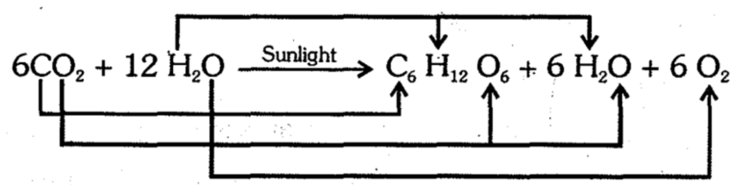
Ruben, Hasid and Kamen :

They proved that the O_2 evolved by the green plant comes from H_2O, not from CO_2 by using radio isotopic techniques.

This can be expressed as :

$$6CO_2^{16} + 12H_2O^{18} \xrightarrow[\text{Pigments}]{\text{Sunlight}} C_6H_{12}O_6^{16} + 6H_2O^{16} + 6O_2^{18}$$

“"The correct equation that would represent the overall process of photosynthesis is therefore"



Where does photosynthesis take place?

- Photosynthesis does take place in the green leaves of plants but it does so also in other green parts of the plants.

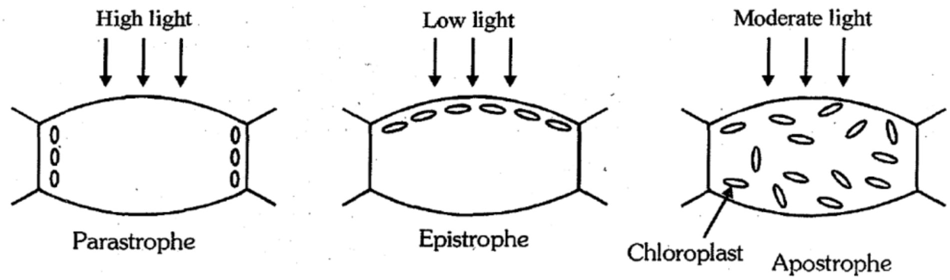
Ques.	Can you name some other parts where you think photosynthesis may occur?
Ans.	Stem of herbaceous plants, green sepals of flowers, of unripe fruits of green tomato, green chilly.

Alignment of chloroplasts:

Ques.	When do you think the chloroplasts will be aligned with their flat surfaces parallel to the walls?
Ans.	Chloroplasts are aligned with the longitudinal walls of mesophyll cells with their edges only towards bright light. This position is called **parastrophe**.

Ques.	When would they be perpendicular to the incident light?
Ans.	In moderate light, chloroplasts arrange themselves perpendicular to the incident light. The arrangement is called **epistrophe**.

- In low light, chloroplasts arrange irregularly in the mesophyll cells. It is called **apostrophe**.



Various kinds of alignment of chloroplasts

- Chloroplasts are those cell organelles in which photosynthesis takes place. Pigments are located in the membranes of thylakoids. Within the chloroplast there is the membranous system consisting of grana, the stroma lamellae, and the fluid stroma. There is a clear division of labour within the chloroplast.

Chloroplast	
Membrane system	**Fluid stroma**
Grana lamellae **Stroma lamellae** The membrane system is responsible for trapping the light energy and also for the synthesis of ATP and NADPH. These reactions, directly light driven are called **light reactions** (photochemical reactions).	In stroma, enzymatic reactions incorporate CO_2 into the plant leading to the synthesis of sugar, which in turn forms starch. These are not directly light driven but are dependent on the products of light reactions (ATP and NADPH). Hence, to distinguish and are called, by convention, as **dark reactions** (carbon reactions).

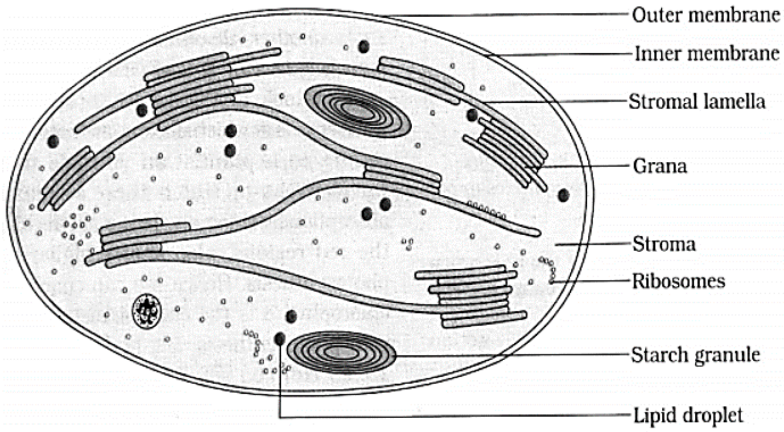


Fig. Diagrammatic representation of an electron micrograph of a section of chloroplast

How many pigments are involved in Photosynthesis

Leaf pigments can be separated from any green plant through paper chromatography, and the picture obtained is called chromatogram.

Chromatographic separation of the leaf pigments shows that the colour we see in leaves is not due to a single pigment but due to four pigments :

1. Chi - a (Bright green or blue green)
2. Chi - b !Yellow green)
3. Xanthophylls (Yellow)
4. Carotene (Yellow orange)

Bacteriochlorophyll or Bacteriopurpurin :

It is purple colour pigment, molecular formula is C55H740 6N4Mg. It occurs inside purple bacteria.

Bacterioviridin or chlorobium chlorophyll :

It is a green colour pigment, occur inside green bacteria.

Types of pigments :

(A) Chlorophylls (B) Carotenoids (C) Phycobillins

(A) CHLOROPHYLLS :

They are green colour pigments and occur inside chloroplast. These pigments are lipid in nature, insoluble in water and soluble in organic solvents.

Types of chlorophyll :

1. Chlorophyll-a

- Its a bluish green or bright green pigment with molecular formula $C_{55}H_{72}O_5N_4$ Mg.
- Chlorophyll-a is a universal photosynthetic pigment

  Reason : Present in every photosyntehtic organism (except eubacteria)
- Chlorophyll-a is a primary photosynthetic pigment.

  Reason : Primary reaction of photosynthesis which involve conversion of light energy into chemical energy (ATP and NADPH) is mediated by chi-a molecule (Reaction centre)
- Chlorophyll-a is most abundant photosynthetic pigment.

Synthesis:

Glycine + Succinyl CoA $\longrightarrow$ Protochlorophyll (protochlorophyllide) $\xrightarrow[2H]{Light}$ Chlorophyll-a

Glutamic acid $\rightarrow$ Chlorophyll-a

Three minerals are essentail for chlorophyll synthesis namely Mg, Fe and N (Mg and N are structural constituent)

Light is compulsory for chlorophyll synthesis in Angiosperms.

Structure of chlorophyll-a :

Structure of chl-a look like tadpole.

Structure of chlorophyll:

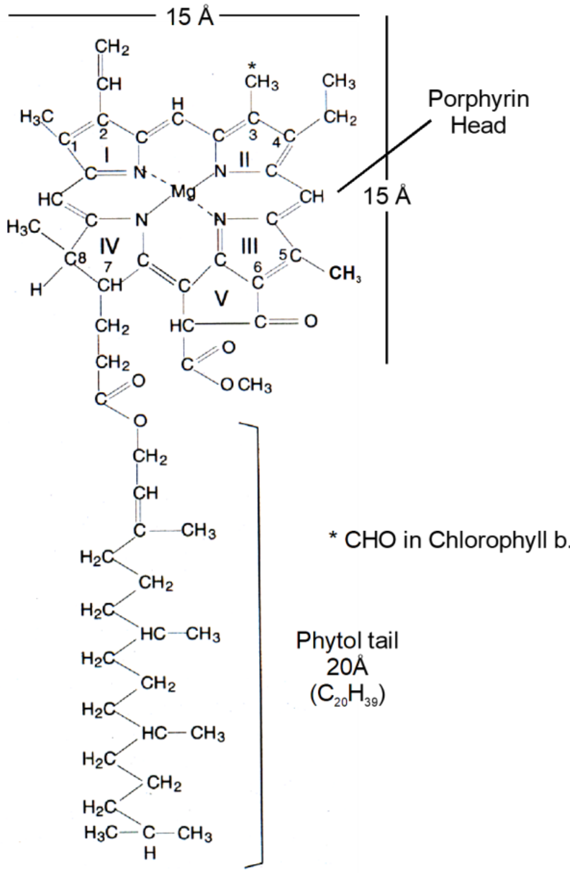


Fig : Structure of chlorophyll a

Tadpole

Porphyrin Head
- Size = 15 × 15 Å
- It is hydrophilic and acidic in nature
- Its a tetrapyrole structure
- Mg is held by 2 coordinate and 2 covalent bonds

Phytol Tail ($C_{20}H_{39}OH$)
- Size = 20 Å long
- It is hydrophobic and alcoholic in nature
- Tail remain embedded in lipid bilayer of thylakoid membrane.

2. Chlorophyll-b

It is yellow green pigment, molecular formula is $C_{55}H_{70}O_6N_4$ Mg.

It is structurally similar to chi-a, except it has –CHO group in place of $-CH_3$ at III position of II pyrrole ring.

3. Chlorophyll-c

Chlorophyll-c lacks phytol tall.

4. **Chlorophyll-d**

5. Chlorophyll-e

Types of photosynthetic pigment in various groups of plants

S.No.	Photosynthetic pigment	Colour	Distribution
	Chlorophylls		
1	Chlorophyll a ($C_{55}H_{72}O_5N_4Mg$)	Blue green	All green plants except bacteria
2	Chlorophyll b ($C_{55}H_{70}O_6N_4Mg$)	Yellow green	All higher plants and green algae
3	Chlorophyll c ($C_{35}H_{32}O_5N_4Mg$)	Green	Diatoms
4	Chlorophyll d ($C_{54}H_{70}O_6N_4Mg$)	Green	Red algae
5	Bacteriochlorophyll ($C_{55}H_{74}O_6N_4Mg$)	Purple	Bacteria
6	Bacterioviridin ($C_{55}H_{74}O_6N_4Mg$)	Green	Bacteria
	Carotenoids		
1	Carotenes ($C_{40}H_{56}$)	Orange	Algae and higher plants
2	Xanthophylls ($C_{40}H_{56}O_2$)	Yellow	
	Phycobilins		
1	Phycoerythrin	Red	Red algae
2	Phycocyanin	Blue	Red algae and blue green algae

(B) CAROTENOIDS:

- Most of the carotenoids are yellow or orange in colour and are soluble in lipids. They protect chlorophyll from photo-oxidation. Thus they are called **protective pigments** or **shield pigments**. They are of two types.

(a) Carotene:

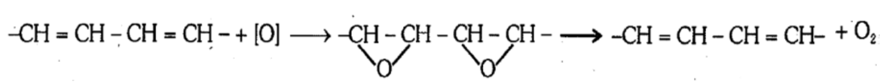
- They are orange in colour. They are hydrocarbon with a general molecular formula $C_{40}H_{56}$.
- **Wackenroder (1831)** firstly isolated a carotenoid from the carrot roots and called carotene (β–carotene)
- Three major isomers of carotene are α - carotene, β - carotene, γ - carotene.
- **Lycopene ($C_{40}H_{56}$) is a carotene which is found in tomato.**

(b) Xanthophyll:

- They are also called **carotenols**. They are Yellow in colour. They are oxygenated derivatives of carotenes, eg. $C_{40}H_{56}O_2$ - Lutein.
- Other important xanthophylls are-**Cryptoxanthin, Vialoxanthin, Zeaxanthin, Flavoxanthin and Fucoxanthin**. **Fucoxanthin** is found in **brown algae.**
- **Xanthophyll and carotene are found in 2 : 1 ratio in juvenile leaves**.

Function of carotenoids :

1. They are accessory pigments and make photosynthesis more efficient by absorbing different wavelengths of light.
2. They protect chi-a from photo oxidation and they also protect photosynthetic machinery by converting lethal nascent oxygen into unharmful molecular oxygen, thus called shield pigments.



3. β-carotene is acts as a precursor of vitamin-A

$C_{40}H_{56} + 2H_2O \longrightarrow 2C_{19}H_{27}CH_2OH$

β–carotene vitamin-A

4. They help in entomophilly and zoochory.

(C) PHYCOBILINS:

- They are usually found in Red algae and Blue green algae.
- They are soluble in water. They are strongly combined with proteins so they are also called **Biliproteins.These are found inside submicroscopic structures called phycobilisomes.**

They are of three types:

1. **Phycocyanin - Blue coloured**
2. **Phycoerythrin - Red coloured**
3. **Allophycocyanin - Blue coloured**

- Phytochrome is a biliprotein which is found in higher plants.
- Phycobilins absorb sunlight and transfer to the chl a. Thus they are accessory pigments.

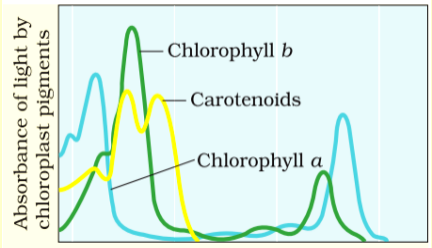
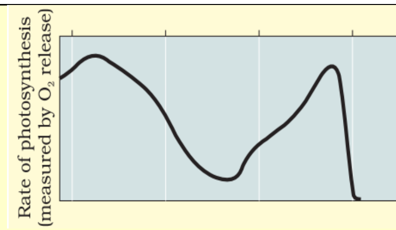
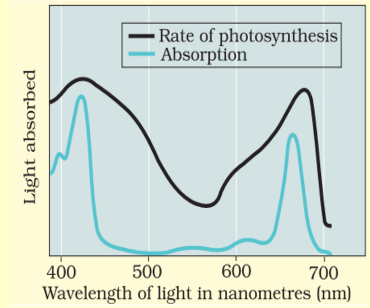
Special points :

- **Etiolation** : Yellowing of leaves due to deficiency of light.
- **Phytochrome** : It is a proteinaceous (chromoprotein) pigment in angiosperms and responsible for seed germination and flowering.

Terminology:

1. **Absorption and action spectra: Visible light has wavelength range of 3900 Å - 7600 Å. The particles of visible light are called photon.**

   Out of seven colours (VIBGYOR) of visible light, green light remain unabsorbed and is reflected back imparting green colour to the leaves.

 Wavelength of light in nanometres(nm)	 Wavelength of light in nanometres(nm)	
Fig. (a) Graph showing the absorption spectrum of chlorophyll a, b and the carotenoids.	Fig. (b) Graph showing action spectrum of photosynthesis.	**Fig. (c)** Graph showing action spectrum of photosynthesis superimposed on absorption spectrum of chlorophyll a.

Absorption spectrum	Action spectrum
1. The graph showing the amount of different wavelengths of light absorbed by a substance is called absorption spectrum. 2. Chl-a absorbs maximum blue followed by red region of spectrum.	1. It is a graph showing actual rate of photosynthesis measured in terms of O_2 production at different wavelength of light. 2. It is maximum in Red followed by blue and minimum in green light.

Ques.	Can you say that there is a complete one-to-one overlap between the absorption spectrum of chlorophyll a and the action spectrum of photosynthesis?
Ans.	No

2. Quantum requirement & Quantum yield:

- Number of light quanta required for the production of one molecule of O_2 is called **Quantum requirement**. Its value is 8.
- The number of oxygen molecules produced per quantum of light absorbed is called **Quantum yield**. It is $\frac{1}{8} = 12.5\%$.

3. Red drop & Emerson enhancement effect:

- Emerson while determining the quantum yield of photosynthesis in **Chlorella** by using monochromatic light of different wavelengths, noticed a sharp decrease in quantum yield at wavelength greater than 680 nm. The fall in photosynthetic yield beyond red region of spectrum is called **Red drop.**
- Emerson further supplied additional shorter wavelengths of light along with far red light (more than 680 nm) He found that quantum yield increased. It is called **Emerson enhancement effect.**
- **The experiment carried by Emerson indicated the existence of two pigment systems**.

MECHANISM OF PHOTOSYNTHESIS:

- The mechanism of photosynthesis is divided into two steps.

1. Light reaction 2. Dark reaction

- **Blackman** firstly reported the existence of light and dark reaction in photosynthesis. The following two evidences confirm the existence of light and dark reactions in photosynthesis.

(i) Intermittent light experiment:

- **Warburg (1919)** conducted an experiment on plant with continuous and intermittent light. The rate of photosynthesis was found to be greater in intermittent light as compared to continuous light. It shows the existence of two steps in photosynthesis a light dependent reaction and another light independent reaction.