PHOTOSYNTHESIS

- It is the physico-chemical process on which the every existence of life on this planet depends.
- It is an **endergonic** reaction and **anabolic** process.
- It is synthesis of carbohydrates from **CO_2** and **H_2O** by utilising the light energy in which O_2 is the bye product.
- The overall reaction of photosynthesis can be represented by the equation:
- $6CO_2 + 12H_2O \xrightarrow{\text{Light and Chlorophyll}}$

  $C_6H_{12}O_6 + 6H_2O + 6O_2$
- From carbohydrates, the other organic substances of the plant are formed.
- Green plants utilise only **1%** of solar energy that falls on this planet to fix **2 billion tones** of CO_2 every year.
- The algae of oceans carry out **90%** of global photosynthesis.

Chloroplast

- It is double membrane bound cell organelle involved in photosynthesis.
- It has two smooth surfaced, selectively permeable membranes with periplastidial space between them.
- The enzyme rich region surrounded by inner membrane is called as **Stroma**. It is involved in dark reaction of Photosynthesis.
- The flattened sack like structures of stroma are known as Thylakoids.
- Stack of thylakoids is known as **Granum**.
- The region where one granum is in contact with other granum is called as **appressed region.**
- Grana are linked by unstacked thylakoids known as **Stroma lamellae** or **Fret membranes**.
- The cavity of each thylakoid is called as **Lumen** or Intrathylakoid space.
- Thylakoid membrane has two structurally different photosynthetic units called **Photo System I** and **Photo system II.**

Photo System

- Each photosystem has two components known as **Reaction centre** and **Antenna – Chlorophyll complex** or **Light Harvesting Complex.**
- Reaction centre is also called as core complex and consists of highly specialised form of **Chlorophyll a.** It is P 700 in Photo system I and P 680 in Photo system II. It converts light energy into chemical energy.
- Light harvesting complex is present around the reaction centre and consists of several chlorophyll and other pigments molecules associated with proteins. These pigment molecules absorb the light energy and transfer to the reaction centre by **inductive resonance** or **resonance transfer**.

Photosynthetic pigments

- These are three types known as Chlorophylls, Carotenoids and Phycobilins.

1. Chlorophylls

- These are green photosynthetic pigments mainly responsible for photosynthesis.
- Structurally a chlorophyll molecule consists of a **Porphyrin** head and **Phytol tail**.
- Porphyrin head is made of **4 pyrrole groups** attached in cyclic manner. It has a **Mg** atom at the centre.
- Phytol tail is **20 C alcohol** esterified to the **4th pyrrolering** of Porphyrin.
- There are 5 types of chlorophylls known as **a, b, c, d** and **e.**
- **Chlorophyll** a is present in all photosynthetic organisms except bacteria. Its chemical formula is **$C_{55}H_{72}O_5N_4Mg$.** Structurally it has $-CH_3$ group at **3rd Carbon** of **II pyrrole** group. It is **blue green** in colour.
- **Chlorophyll b** is present in Green algae and all higher plants. Its chemical formula is **$C_{55}H_{70}O_6N_4Mg$**. Structurally it has **–CHO** group in place of methyl group of chlorophyll a. it is **olive green** in colour.
- **Chlorophyll c** is present in Brown algae (Phaeophyceae) and Diatoms (Bacillariophyceae).
- **Chlorophyll d** is present in Red algae (Rhodophyceae).
- **Chlorophyll e** is present in Xanthophyceae algae.

2. Carotenoids

- These are terpenoid group of pigments with **orange, yellow** – **purple** colours.
- These are **open chain** compounds with **conjugated double bonds** ending with **ionone** rings. These are of two types known as Carotenes and Xanthophylls.
- Carotenes are non-oxygenated carotenoids or hydrocarbons with chemical formula as **$C_{40}H_{56}$.** The common types of carotenes are **α- carotene, β- carotene** and **Lycopene.**
- Xanthophylls are oxygenated carotenoids with the chemical formula as **$C_{40}H_{56}O_2$**. The most common types are **Lutein, Zeaxanthin** etc.

- Carotenoids absorb the light energy and transfer it to reaction centre. They protect the chlorophylls from photo bleaching.

Phycobilins

- These are **linear tetrapyrrole** group of pigments without Mg. They resemble chlorophylls.
- They are red coloured **Phycoerythrin** and blue coloured **Phycocyanin.**
- These are present only in **Red algae** and **Blue-Green algae.**
- Since carotenoids and phycobilins cannot utilise the solar energy directly they are called as **accessory pigments.**
- About **95 – 99 %** of photons trapped by accessory pigments are transferred to reaction centre.
- **Absorption spectrum:** it is the graph that indicates the absorption of different wavelengths of light by pigments. It is known by using **Spectrophotometer.**
- **Action spectrum:** It is the graph that shows the rate of photosynthesis at different wavelengths of light.

Light

- In photosynthesis only visible light is usually utilised. Its wavelength ranges from **390 – 760 nm.** It is known as **Photosynthetically Active Radiation.**
- Light has wave and particle nature. Each particle is called as **Photon** and the packet of energy present in each photon is **Quantum.**
- Energy of photon is inversely proportional to its wavelength. Blue light carries more energy than red light.
- Upon absorption of light by ground state chlorophyll molecule, it reaches a high-energy state known as excited state (**Chl***). It is represented as **Chl + hυ → Chl*.**
- Chlorophyll molecule can be in excited state for $\mathbf{10^{-9}}$ seconds. This **excitation energy** is used in photosynthesis.

Mechanism of Photosynthesis

- It has two stages known as Light reaction and dark reaction. **Blackman** first reported it.

Light Reaction

- It takes place in the grana (thylakoids) of chloroplast.
- It is also known as Hill reaction and Photochemical reaction.
- It is faster than dark reaction.
- It takes place only in the presence of light.
- In this, light energy is converted into chemical energy (ATP and NADPH).
- It is studied under 4 headings known as Hill's reaction, Emerson Enhancement Effect, PS I and PS II electron transport and Proton translocation and Photophosphorylation.

1. Hill's Reaction

- It is release of O_2 by illuminated chloroplasts in the presence of a hydrogen acceptor or oxidising agent.
- Hill used Potassium ferric oxalate as hydrogen acceptor. Hence it is known as Hill Reagent.
- Hill didn't demonstrate the release of oxygen from water.
- Hill reaction can be represented as $2\ H_2O + 2\ A \rightarrow 2\ AH_2 + O_2$. In this reaction A is Hill oxidant. It shows that Oxygen is released from water but not from carbon dioxide.
- **Ruben** and **Kamen** demonstrated the release of oxygen from water but not from carbon dioxide by using O^{18} isotope.
- In bacterial photosynthesis **H_2S** is the electron donor. Hence there is no liberation of oxygen in bacterial photosynthesis. It can be represented as $2H_2S + CO_2 \rightarrow 2S + CH_2O + H_2O$.

2. Emerson's Enhancement Effect

- Emerson conducted experiments on the green alga *Chlorella.*
- When he exposed *Chlorella* to longer wavelength of red light (**> 680 nm**), he observed the decrease in Photosynthetic rate. It is called as **Red drop.**
- Net increase in photosynthesis when *chlorella* is simultaneously subjected to longer and shorter wave lengths of red lights (650 – 680 nm), he observed the net increase in photosynthetic rate. It is termed as Emerson's enhancement effect or Emerson's effect.
- From Red drop and Emerson's enhancement effect, Emerson concluded that two photo systems known as Photosystem I and Photo system II are operated in photosynthetic light reaction.

3. Photo System I and Photo System II

Photo system I	Photo system II
1. It is present in the non-appressed regions of grana thylakoids and stroma thylakoids.	1. It is present in the appressed regions of grana thylakoids.
2. Light harvesting complex has 100 chlorophyll a and chlorophyll b molecules.	2. Light harvesting complex has 250 chlorophyll a and b molecules.
3. Chlorophyll a and chlorophyll b exist in 4:1 ratio.	3. Chlorophyll a and b exist in 1:1 ratio.
4. It has more carotenes	4. It consists of more xanthophylls.
5. Reaction centre is specialised form of chlorophyll a molecule known as P 700.	5. Reaction centre is P 680.

Photosynthetic electron and proton transport

- Photosystem I, photosyetem II and cytochrome complex are involved in the transport of protons and electrons.
- By utilising the light energy the electrons of water are transported to $NADP^+$ through PS II, Cytochrome complex and PS I to form $NADPH+H^+$.
- It has the following steps.

Step I:

- PS II absorbs shorter wave length of red light and its reaction centre P 680 is excited and expels a pair of electrons and becomes $P\ 680^+$.

Step II:

- The liberated electrons are accepted by the primary electron acceptor **Pheophytin** or **Pheo**. Pheo is Mg less chlorophyll a molecule. 2 H atoms replace Mg.

Step III:

- **$P\ 680^+$** is strong oxidant. It pulls electrons from H_2O through **Oxygen evolving complex** present on the lumen side of thylakoid membrane. OEC consists of few proteins, 4 Mn^+, Ca^{+2} and Cl^- ions. It is associated with Photosystem II. The splitting of water and consequent release of oxygen in the presence of light is known as Photolysis. The protons of this reaction are released into the lumen. It is represented as follows.

$$H_2O \xrightarrow{\text{Light}} \frac{1}{2}O_2 + 2H^+ + 2\,e^-$$

Step IV:

- Electrons of Pheophytin enter into Q cycle.
- The electron of pheo is accepted by Plastoquinone$^-$ through Quinone during which it also accepts 2 H^+ from stroma to form PQH_2.
- PQH_2 is oxidised and the two protons are released into the lumen and forms Plastosemiquinone. One electron is given to **cytochrome f** via an **Fe-Sulphur** protein.
- Plastosemiquinone is oxidised and forms PQ. The electron is accepted by **cytochrome b_6**. Cytochrome b_6 gives the electron to PQ to form PQ^-.
- In this way for each electron transported there is transport of 2 H^+ from stroma to lumen through Q cycle.

Step V:

- The electron of cytochrome **f** is given to a **Cu containing bluish protein** mobile electron carrier known as **Plastocyanin**. PC is present towards the lumen side of thylakoid membrane.

Step VI:

- During this time, PS I absorbs longer wavelength of red light and its reaction centre P 700 is excited and expels the electrons, which are accepted by an **Fe-S containing unknown protein.**
- P 700 becomes P 700^+.
- These electrons are accepted by Ferridoxin, which is also an Fe-S containing protein.

Step VII:

- Now the P 700^+ accepts two electrons from reduced PC and becomes P 700.

Step VIII:

- By the catalytic activity of Fd – NADP oxidoreductase, electrons are transferred to $NADP^+$ to form NADPH + H^+ to complete non – cyclic electron transport.
- Non – cyclic electron transport can be inhibited between PS II and PS I by DCMU (Dichloro Phenyl dimethyl urea).
- For each pair of Non – cyclic electron transport from Water to $NADP^+$, there is accumulation of 6 H^+ in the lumen. They are 2 from photolysis of water and 4 from stroma to lumen through PQ.
- The energy rich protons are utilised for the synthesis of ATP.

Photophosphorylation

- It is synthesis of ATP from ADP and Pi in the presence of light.
- **Daniel Arnon** discovered it. ATP are synthesised in accordance with Peter Mitchel's Chemiosmotic hypothesis.
- Peter Mitchel got Nobel prize in 1978 for proposing Chemiosmotic theory.
- This theory states that the energy rich protons are responsible for synthesis of ATP in the CF particle of Thylakoid membrane.
- In the presence of light, lumen shows high accumulation of Protons obtained from photolysis of water and transport of protons from stroma to lumen through PQ.
- Since the proton concentration is very high in lumen, the protons try to move into stroma through thylakoid membrane. But thylakoid membrane is impermeable to Protons.
- Hence the protons move through CF particle. CF particle has a hydrophobic tail embedded in the thylakoid membrane known as **CF_o** and projected head known as **CF_1** or ATPase complex.
- CF_o acts as **proton channel** and CF_1 as catalytic site that **synthesises ATP.**
- For every 3 H+ transported through CF particle, there is synthesis of 1 ATP. Hence for the transport of each pair of electrons, there is accumulation of 6 protons. When these 6 protons are transported through CF there is synthesis of 2 ATP.
- For each pair of electrons non – cyclic transport there is synthesis of 1 NADPH + H^+ and 2 ATP.

Cyclic electron transport and Cyclic - Photophosphorylation

- *Frankel* discovered it in *Rhodospirillum rubrum.*
- It is operated when only longer wavelength of red light is available.
- It is additional mechanism to provide additional ATP to carry out chloroplast activities.
- PS I absorbs longer wavelength of red light and its reaction centre P 700 is activated and expels an electron to become P 700^+.
- Ferridoxin accepts the expelled electron. From Fd it moves to Cytochrome b_6 and then to PQ (Q cycle). From PQ the electron moves to Cytochrome f.
- Plastocyanin accepts the electrons from Cytochrome complex. PC gives the electron to P 700^+ to form P 700.
- For each pair of electrons cyclic transport, there is pumping of 4 protons from stroma to lumen. These 4 protons are sufficient to form 1 ATP in CF particle.

Differences between Cyclic and Non – cyclic electron transport

Cyclic electron transport	*Non – cyclic electron transport*
1. Only PS I is involved	1. Both PS I and PS II are involved simultaneously.
2. Only longer wavelength of red light is used.	2. Utilises both longer and shorter wavelengths of red light.
3. Electrons move in	3. Electrons move in

cyclic manner. 4. Photolysis of water does not occur and hence no liberation of oxygen. 5. It is not inhibited by DCMU 6. For each pair of electrons transport only one ATP is formed but not NADPH	zig-zag manner (**Z – scheme**). 4. Water is oxidised and hence oxygen is liberated. 5. It is inhibited by DCMU 6. 1 NADPH and 2 ATP are formed for each pair of electrons transport.

Dark Reaction

- It takes place in the stroma of chloroplast.
- **Blackman** discovered it.
- It is not directly dependent on light.
- It is mainly regulated by temperature. Hence it is also known as **thermochemical** reaction.
- It utilises NADPH and ATP produced in dark reaction for the fixation of CO_2 into carbohydrates through various biochemical reactions. Hence the chemical energy is known as **Assimilatory Power.**
- It takes place in three different biochemical pathways known as Calvin cycle, Hatch and Slack pathway and CAM pathway.

Calvin Cycle (C_3 cycle)

- It is also known as **Reductive Pentose Phosphate Pathway** and **Photosynthetic Carbon Reduction Cycle.**
- **Melvin Calvin, Andrew Benson** and **James Bassham** discovered it in the green alga **Chlorella** by using Autoradiography technique and radioactive carbon ($^{14}CO_2$).
- They transferred algal cultures to **80%** hot methanol with durations of time ranging from **2 – 60 seconds.**
- For this monumental work **Calvin** was given Nobel Prize in 1961.
- This cycle is operated either directly or indirectly in all photosynthesising organisms.
- It has three stages known as 1. Carboxylation stage, 2. Reduction stage and 3. Regenaration stage.

1. Carboxylation Stage

- In the only biochemical reaction of this stage 3 molecules of CO_2 is accepted by 3 molecules of Ribulose 1, 5 – bisphosphate to form 6 molecules of the first stable 3C compound known as 3 – phosphoglyceric acid.
- It is catalysed by the most abundantly present enzyme of Chloroplast stroma known as RuBP carboxylase/oxygenase abbreviated as RUBISCO. This enzyme accounts for 25 – 50 % of soluble proteins of chloroplast stroma and most abundantly present protein in the plant kingdom.
- **3** CO_2 + **3** RuBP (5C) $\rightarrow$ **6** 3 – phosphoglyceric acid (3C)
- Since the first stable compound of this pathway is a 3C compound, it is known as C_3 cycle.

2. Reduction stage

- It has two biochemical reactions that utilise both **ATP** and **NADPH.**
- In the first reaction 6 PGA are converted to 6 molecules of 1, 3 – Bisphospho Glyceric acid in the presence of enzyme phosphoglycerate kinase
- 6 3 – PGA + 6 ATP $\rightarrow$ 6 1, 3 – bis PGA + 6 ADP
- Six molecules of 1, 3 bis – phosphoglyceric acid is reduced to 6 molecules of Glyceraldehyde 3 – phosphate by Glyceraldehyde – 3 – phosphate dehydrogenase by utilising 6 molecules of NADPH + H^+
- 6 1, 3 – bis PGA + 6 NADPH + $H^+ \rightarrow$ 6 Glyceraldehyde – 3 Phosphate + 6 $NADP^+$
- Out of 6, one molecule of Glyceraldehyde – 3 phosphate is transported to **cytosol** where it is involved in the formation of **hexoses** or **Sucrose.** The remaining 5 molecules of GAP is involved in the regeneration of 3 molecules of RuBP. It shows that hexoses are synthesised in the **cytosol** but not in the **chloroplast.**

3. Regeneration Phase

- It has several biochemical reactions during which 4, 5, 6 and 7C sugars are formed.
- In the first reaction of this phase 2 molecules of GAP is converted to its isomeric form Dihydroxy Acetone Phosphate by the action of triose phosphate isomerase.

  2 Glyceraldehyde – 3 – phosphate $\leftrightarrow$ 2 Dihydroxy acetone phosphate.
- One molecule of GAP condenses with one molecule of DHAP to form one molecule of 6C compound Fructose 1, 6 – bis phosphate. It is catalysed by the enzyme aldolase.

  1 GAP + 1 DHAP $\rightarrow$ 1 Fructose 1, 6 – bis phosphate
- One molecule of FBP is dephosphorylated to Fructose – 6 – phosphate by the action of Fructose 1, 6 – bis phosphatase.

  1 FBP $\rightarrow$ 1 Fructose – 6 – phosphate + Pi
- One molecule of FMP reacts with one molecule of GAP to form one molecule of 4C compound Erythrose – 4 – phosphate and one molecule of 5C compound Xylulose – 5 – phosphate by transketolase.

  1 FMP + 1 GAP $\rightarrow$ 1 Erythrose – 4 – phosphate + 1 Xylulose – 5 – phosphate.
- One molecule EMP combines with one molecule of DHAP to form one molecule of 7C compound Sedoheptulose 1, 7 – bis phosphate. It is catalysed by trans aldolase.

  1 EMP + 1 DHAP $\rightarrow$ 1 Sedoheptulose 1, 7 – bis phosphate
- SBP undergoes dephosphorylation by the action of Sedoheptulose 1, 7 bis phosphatase to form one molecule of Sedoheptulose – 7 – phosphate.

  1 SBP $\rightarrow$ 1 SMP
- One molecule of SMP reacts with one molecule of GAP in the presence of transketolase to form one molecule of XMP and one molecule of Ribose – 5 – phosphate (RMP).

  1 SMP + 1 GAP $\rightarrow$ 1 Ribose – 5 – phosphate + 1 XMP
- 2 molecules of XMP is converted to its epimeric form Ribulose – 5 – phosphate by the action of Epimerase.

  2 XMP $\rightarrow$ 2 Ribulose – 5 – phosphate
- One molecule of RMP is also converted to RuMP by the action of the enzyme Ribose – 5 – phosphate isomerase.

  1 RMP $\rightarrow$ 1 RuMP
- 3 molecules of RuMP is converted to 3 molecules of RuBP by the action of RuMP kinase by utlising 3 ATP.

  3 RuMP + 3 ATP $\rightarrow$ 3 RuBP + 3 ADP

Energitics of Calvin Cycle

- For the fixation of 3 molecules of CO_2 to form a triose, 6 NADPH + H^+ and 9 ATP are utilised. Similarly for the formation of one hexose 12 NADPH + H^+ and 18 ATP are required.

II. Hatch and Slack pathway

- It is also known as **C_4 pathway** and **β - carboxylation pathway.**
- **Kortschak, Hartt** and **Burr** discovered the formation of 4C dicarboxylic acids such as **Aspertic acid** and **Malic acid** during dark reaction in **Sugarcane.**
- Hatch and Slack confirmed this and traced the biochemical reactions of this pathway in sugar cane.
- **Prof. Rama Das** did exhaustive work on C_4 plants from out country.
- It is seen in tropical and subtropical plants that grow in temperatures ranging from **30 – 45°C.**
- It is seen in about **1500** species belonging to **19** families of angiosperms.
- Plants with this pathway are better equipped to withstand drought and show more photosynthesis even in water stress conditions.
- It shows that these are more evolved than C_3 plants.
- Since the first formed stable compound is a 4C compound, this cycle is known as C_4 cycle and the plants are known as C_4 plants.

Structural speciality of C_4 leaf

- The most distinct feature is presence of bundle sheath with chloroplasts in the leaves. It is like a wreath around the vascular bundle. Hence such anatomy is called as **Kranz anatomy.**
- Bundle sheath may be **single layered** as in Maize or **double layered** as in Sugarcane. If two layered, the outer one **is green** and the inner one is **thick walled** and called as **mestomal sheath.**
- Mesophyll cell chloroplasts are granal and starch lacking but the bundle sheath cell chloroplasts are grana - lacking and starch - rich. Such feature is known as **chloroplast dimorphism.**
- These two chloroplasts show division of labour.

Reactions

1. In the first reaction, 3C compound of mesophyll cell chloroplast stroma known as Phosphoenol Pyruvic acid accepts a molecule of CO_2 in the form of bicarbonate ions in the presence of PEP carboxylase to form the first stable 4C compound Oxalo Acetic Acid.

   CO_2 + Phosphoenol Pyruvic acid $\rightarrow$ Oxaloacetic acid + H_3PO_4 + H_2O
2. OAA is converted to Malic acid by Malate dehydrogenase by utilising NADPH + H^+.

   OAA + NADPH + $H^+ \rightarrow$ Malic acid + $NADP^+$

- In some C_4 plants, Aspertic acid is formed by transamination reaction.
- Based on the type of compound formed from OAA, C_4 plats are classified into Malate formers and Aspertate formers.

1. Malic acid formed in mesophyll cell is transported to bundle sheath cells through plasmodesmata. This acid undergoes oxidative decarboxylation to Pyruvic acid (3C compound) by malate decarboxylase and regenerates NADPH + H^+.

   Malic acid + $NADP^+ \rightarrow$ Pyruvic acid + NADPH + H^+ + CO_2
2. The liberated CO_2 is accepted by RuBP of bundle sheath cell chloroplast stroma to run Calvin cycle during which ATP and $NADPH_2$ are utilised.
3. Pyruvic acid formed in the 3rd reaction is transported back to mesophyll cell where it is phosphorylated to Phosphoenol Pyruvic acid by Pyruvate dikinase by utilising 2 ATP for each molecule conversion. In this way PEP is regenerated.

   Pyruvic acid + 2 ATP + 2 Pi $\rightarrow$ Phosphoenol pyruvic acid + 2 AMP + 2 PPi

- There are two carboxylations in this pathway. One in mesophyll cell chloroplast and the other one in bundle sheath cell chloroplast.
- 12 $NADPH_2$ and 30 ATP are utilised for the formation of one hexose by fixing 6 CO_2. Hence an excess of 12 ATP are used for the formation of one hexose when compared with C_3 cycle.

Differences between C_3 and C_4 pathways

C_3 Pathway	C_4 Pathway
1. Usually seen in temperate plants and some tropical plants.	1. Occurs in tropical and sub-tropical plants.
2. Leaves do not show Kranz anatomy.	2. Leaves show Kranz anatomy.
3. Green cells show only one type of chloroplasts with grana.	3. Mesophyll cells have granal and bundle sheath cells have agranal chloroplasts (Chloroplast dimorphism).
4. Only Calvin cycle is operated.	4. C_4 pathway in mesophyll cells and C_3 pathway in bundle sheath cells.
5. Primary CO_2 acceptor is RuBP	5. Primary CO_2 acceptor is PEP
6. The first formed stable compound is Phosphoglyceric acid.	6. The first formed stable compound is Oxaloacetic acid.
7. Less efficient in fixing CO_2.	7. More efficient.
8. Show high photorespiration.	8. Not detectable.
9. Optimum temperature is 15 – 25°C.	9. 30 – 45°C.
10. Photosynthetic yield is low to average.	10. High.
11. 18 ATP are used for the formation of one	11. 30 ATP are utilised. 18 in bundle sheath cells

molecule of glucose. 12. Less efficient in water usage. 13. CO_2 compensation point is very high.	and 12 in mesophyll cell. 12. High. 13. Low.

Factors Influencing Photosynthesis

A. External Factors

1. Light: Without light there is no photosynthesis. Light influences photosynthesis in terms of intensity, quality and duration.

- Only visible light (390 – 760 nm) is used in photosynthesis.
- High photosynthesis is shown is Red light. Later in blue light and almost lacking in green light. Green light is reflected back.
- With increase in light intensity photosynthetic rate increases upto certain level.
- Plants that grow in shade are called as **Sciophytes.** They require low light intensity.
- Plants that grow in high light intensity or direct sunlight are called as **Heliophytes.**
- Oxidation of chlorophylls at high light intensity is called as **Solarisation**. Carotenoids protect the chlorophylls from high light intensity.
- Light intensity at which the release of O_2 is equivalent to CO_2 absorption is called as **Light compensation point.**
- C_4 plants show high photosynthesis at high light intensity than C_3 plants.
- Photosynthetic rate is more in intermittent light than continuous light of same duration.

2. Temperature

- Influence of temperature on photosynthesis differs from plant to plant.
- Plants of temperate regions such as Conifers can perform photosynthesis even at **–6°C.**
- Some blue green algae and bacteria can perform photosynthesis at **70°C.**
- Usually with increase in temperature from 10°C to 40°C, the photosynthetic rate increases.
- Influence of temperature on photosynthesis is different in C_3 and C_4 plants.

3. CO_2 concentration

- CO_2 is the main raw material for photosynthesis.
- Atmosphere has 0.03% CO_2 concentration by volume.
- With increase in concentration up to 1%, the photosynthesis increases.
- At more than 1% concentrations, the stomata are closed and such concentrations are toxic to plant. Hence photosynthesis at higher concentrations of CO_2 is negligible or zero.
- CO_2 concentration at which the photosynthetic rate is equal to respiration rate is called as **CO_2 compensation point**. It is more for C_3 plants than C_4 plants.

4. O_2 Concentration

- It is released in photosynthesis as a result of photolysis of water but not utilised.
- Warburg observed decrease in photosynthesis with increase in oxygen concentration. It is known as **Warburg's effect.**
- Warburg's effect is due to **photorespiration**, which is a waste process in C_3 plants.

5. Water

- With decrease in water availability, photosynthesis also decreases.
- Water deficiency retards **cellular expansion**, CO_2 absorption due to stomatal closure and enzymatic activity.
- Water has an important role in photosynthesis because it provides electrons and protons and source of oxygen liberated in photosynthesis.

B. Internal Factors

1. Chlorophyll

- With increase in the amount of chlorophyll the amount of photosynthesis also increases.
- In the dark photosynthesis decreases due to **'etiolation'**. Etiolation is excessive elongation of internodes, poor development of leaves and pale colouration of plant.
- With increase in age, the chlorophyll content also decreases. Hence photosynthesis also decreases.

2. Internal structure of Leaf

- With increase in thickness of cuticle and epidermis, decrease in the number of stomata the photosynthetic rate also decreases.
- Leaves with less mesophyll show less photosynthesis.

3. Deposition of End products

- Accumulation of photosynthates in the green cells leads to decrease in photosynthesis due to **Feed Back inhibition.**
- For maximum photosynthesis, the photosynthates should be immediately translocated.
- Photosynthates translocation is **quicker in C_4 plants** than C_3 plats because the photosynthates formed in bundle sheath cells are at once transported through phloem.

Blackman's Law of Limiting Factors

- Blackman proposed it. It is based on **Liebeg's** law of minimum.
- It is defined as 'When a process is conditioned to its rapidity by a number of separate factors, the rate of the process is limited by the pace of the slowest factor. This factor is called as Limiting Factor.
- At lower concentrations of the limiting factor, with increase in the concentrations of the factor, the rate of photosynthesis increases. At very high concentrations it is not observed.
- At lower CO_2 concentrations, with increase in light intensity the photosynthetic rate increases up to **400 units** of light intensities. Beyond this light intensity, the rate of photosynthesis remains same because the CO_2 concentration is not sufficient. CO_2 concentration becomes limiting factor.
- In higher CO_2 concentrations, again with increase in light intensity, the photosynthetic rate increases up to certain level. Beyond this level there is no further increase in photosynthesis. At this point higher concentrations of CO_2 becomes limiting **factor.**