PHOTOSYNTHESIS IN HIGHER PLANTS

- Photosynthesis is a process in which the synthesis of carbohydrate by chlorophyll containing organisms from CO_2 and water in the presence of light.

$$6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$$

- **Anabolism** - construction of carbohydrate.
- **Endergonic** - Energy consuming process
- **Oxido-reduction** (redox reaction) : During photosynthesis, water becomes oxidised and CO_2 reduced into carbohydrates.

Classification of living organism on the basis of :

1. Their energy source
2. Their carbon source

1. Based on energy source;

i) Phototrophs **-** use light energy to synthesis their organic requirements.
- characterised by the presence of light harvesting pigments

ii) Chemotrophs - use chemical energy for synthesis of organic requirements.

2. Based on carbon source ;

i) Autotrophs - Organisms capable of surviving on CO_2 as their principle carbon source.
- Depends on inorganic carbon source.

A) Photoautotrophs - uses radiant energy of sun to convert CO_2 into organic compounds.

eg. 1. Photosynthetic bacteria

$\rightarrow$ Green sulphur : chlorobium
$\rightarrow$ Purple sulphur : chromatium
$\rightarrow$ Purple non sulphur : Rhodospirillum

- Green sulphur and purple sulphur bacteria - photolithotrophs
  They depend on inorganic source : H_2S (hydrogen donor)
- Purple non sulphur bacteria - Photoorganotrophs
  Depends on organic source : Malic acid / Propanoic acid (H donor)

- Pigments : Bacterio chlorophyll
  Bacterio-viridin

- Possess only a single type of photosystem
- Pigments are arranged in chromatophore - circular membrane arising from plasma membrane
- Utilise infra-red light
- Anoxygenic photosynthesis - without evolution of O_2 during photosynthesis

eg. 2. Cyanobacteria

→ Chlorophyll a were first developed

→ oxygenic photosynthesis started

eg. 3. Photosynthetic protista

→ Chrysophytes : Desmids and Diatoms

→ Dinoflagellates : Gonyaulax

→ Euglenoids : Euglena

b) Chemoautotrophs : uses chemical energy stored in inorganic molecules such as ammonia and nitrites to convert CO_2 into organic compounds.

eg. Nitrifying bacteria

B) Heterotropus : Organisms that depend on an external source of organic compounds. Eg. Animals

SIGNIFICANCE OF PHOTOSYNTHESIS

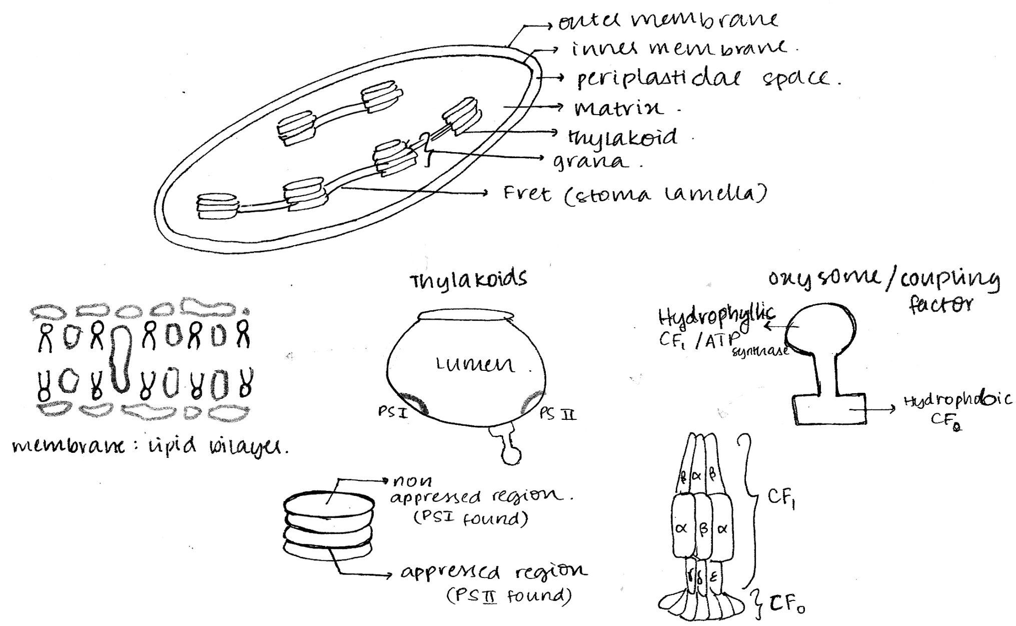
- Provides food to all orgsanisms directly or indirectly.
- Great role in purifying air by consuming CO_2 and releasing an equal amount of oxygen helpful in maintaining percentage of O_2 and CO_2 constantly in the atmosphere.
- Provides huge source of energy for man kind in the form of coal, petroleum, wood etc.

- **Photosynthetic organ : Leaf**
- **Photosynthetic organelle / apparatus : Chloroplast**

Chloroplast

- Term coined by Shimper.
- Semi autonomous and endosymbiont
- Discoid shape in higher plants

STRUCTURE

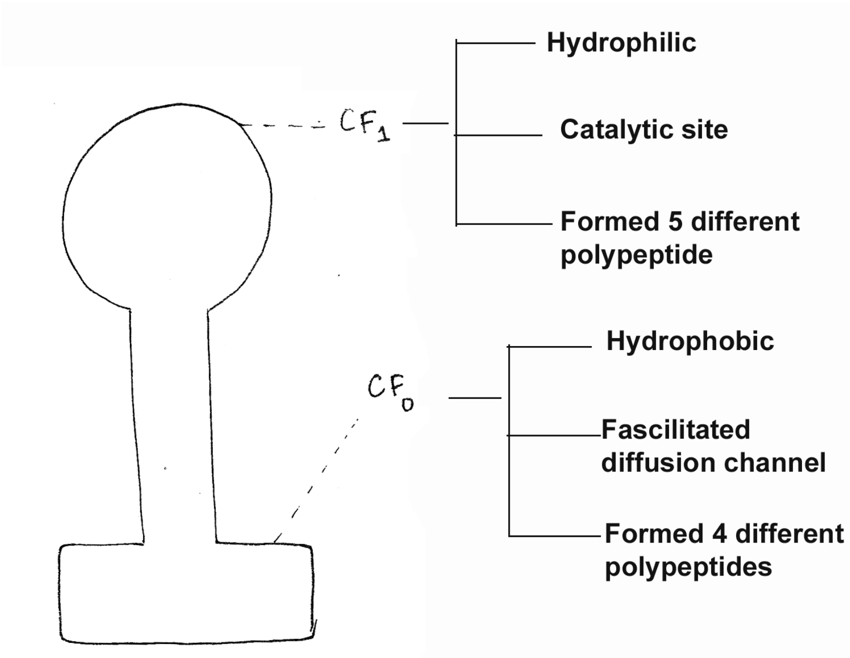


- Chloroplasts are enveloped by two unit membrane
- Internally chloroplast are composed of $\rightarrow$ a system of single membrane bounded **flattened sac like structures** called **Thylakoids**.
  - term coined by Menke.
  - structure is maintained by linolelic acid
  - Highly selectively permeable : allows solvents and some solutes
  - Impermeable to passive flow of protons

GRANA

- Stacks of thylakoids
- Grana are embedded in a colourless matrix : **stroma -** contains DNA (single, circular, ds), RNA, ribosome (70s) and enzymes (RUBISCO)
- Grana are interconnected by loosely arranged thylakoids called stroma lamellae / Fret
- Space inside the thylakoid sac - **LUMEN**
  - It is rich in protons
  - low pH / Acidic

- On the surface of the thylakoid membrane, knob like projections are seen - Oxysome : coupling factor / CF_0 - CF_1 particle / elementary particle / ATP synthase complex.



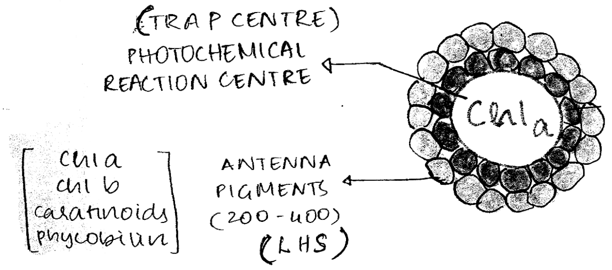
♦ It consists of 2 regions :

CF_1 : Spherical head
- Protrudes towards the stroma
- Hydrophilic
- Catalytic site (ATPsynthase)
- Formed of 5 different polypeptides - $\alpha_3, \beta_3, \gamma, \delta, \varepsilon$

CF_0 : Basal stock
- Embedded in the membrane
- Hydrophobic
- Facilitated diffusion channel
- A channel protein through which protons flow from lumen towards stroma
- Formed of 4 different polypeptides - a, b, b', C_{12} - Regulated by gene present in nucleus

PHOTOSYSTEM

(Special Chl a)



It is an organised structure composed of pigments and proteins that catalysis the conversion of light energy into chemical energy.

LHC : light harvesting complex.

Antenna + CAB proteins

LHS/Antinna → Light harvesting system - All pigment except reaction centre (Chla)

CAB PROTEINS : Chla and b proteins that orient the chlorophyll pigments in a plane suitable for light absorption.

Core complex → Reaction centre + Proteins + Electron carriers

Photosystem = all the pigments + proteins (LHC + core complex)

Photochemical reaction centre / special chlorophyll a / trap centre

→ The transducing region of photosystem where light energy is converted into chemical energy.

P 700 : Reaction centre of PS I

P 680 : Reaction centre of PS II

PS I

- Order of discovery → First
- Found in both stroma lamella and grana thylakoid (grana lamella)
- Found predominantly in non-appressed region of thylakoids (independence surface of thylakoids)
- Absorb light in the region upto 700 nm
- Predominant - chl a (230)

PS II

- Order of discovery → Second
- Found only in grana thylakoid
- Found predominantly in appressed region of grana
  [place where one grana thylakoid is in contact with another]
- Absorb light in the region upto 680 nm
- Chl a and Chl b are equal in number

PAPER CHROMATOGRAPHY

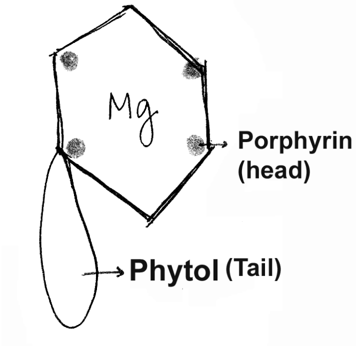
- For the separation of photosynthetic pigments.
- A pigment is a molecule that absorb light of a specific wave length in the spectrum. Pigments are seen as groups called photosynthetic units - **Quantasome (Chlorophylls)**
- Pigments are secondary metabolite.

Chromatogram → bright / blue green : Chlorophyll A

→ yellow → green : Chlorophyll B

→ yellow → orange : Carotenoids

CHLOROPHYLL



- Term coined by Pelletier and Caventou
- Structure was revealed by Willstatler and stoll
- Green pigments
- Absorbs blue, red and violet light
- Dissolved in organic solvents. eg. Acetone, chloroform, petroleum, ether etc.
- % of chlorophyll in a normal chloroplast is 5 - 10%
- Chlorophylls are Mg - porphyrin compounds
- Porphyrin consists of tetra pyrole rings
- Porphyrin head $\rightarrow$ hydrophyllic
- Phytol tail $\rightarrow$ hydrophobic

Essential requirements for the synthesis of chlorophyll.

1. Magnesium
2. Glycine
3. Succinyl co-enzyme A

a) Chlorophyll A

- Universal photosynthetic pigment
- Primary photosynthetic pigment
- Present in antenna, core and reaction centre
- Found in $\rightarrow$ Cyanobacteria
  $\rightarrow$ Chrysophytes
  $\rightarrow$ Dinoflagellates
  $\rightarrow$ Euglenoids
  $\rightarrow$ plant kingdom

Chl a - $C_{55}H_{72}O_5N_4Mg$ (CH_3) - functional group

b) Chlorophyll B

- Secondary light collectors
- Present only in antenna region

- Found in $\rightarrow$ Euglenoids
  $\rightarrow$ Green algae
  $\rightarrow$ Higher plants

$C_{55} H_{70} O_6 N_4 Mg$ (CHO)

c) Chlorophyll C

- Secondary light collectors
- Present in antenna region
- Found in $\rightarrow$ Chrysophytes
  $\rightarrow$ Dinoflagellates
  $\rightarrow$ Brown algae

d) Chlorophyll d

- Secondary light collectors
- Present in antenna region
- Found in Red algae

e) Chlorophyll e

- Secondary light collectors
- Present in antenna region
- Found in members of xanthophyceae. eg. Vaucheria (Algae)

CAROTENOIDS

- Hydrocarbons
- More stable
- Dissolved in fat
- Yellow to orange pigments
- Absorb blue and violet light
- Accessory pigments - Secondary light collectors
- Provide protection to chlorophyll from photo-oxidation/solarisation $\rightarrow$ Shield pigments (protective)
- Destruction of chlorophyll due to high light intensity is called photo-oxidation
- Bifunctional pigments $\rightarrow$ absorptive
  $\rightarrow$ protective

a) CAROTENE

- orange pigment
- β carotene $\rightarrow$ Dominant carotene in higher plants
  $\rightarrow$ Precussor of Vit A

b) XANTHOPHYLL

- yellow pigment
- oxygen containing derivative of carotene
- Lutein - dominant xanthophylls in higher plants
- Violoxanthin - dominant xanthophylls in higher plants
- Zeaxanthin $\rightarrow$ present in maize

PHYCOBILIN

- Accessory pigments
- Absorb and pass energy to chlorophyll
- Dissolved in water
- Present in antenna region

a) Phycoerythrin

- Red pigment
- Found predominantly in red algae
- Present in cyanobacteria $\rightarrow$ Trichodesmium
  $\rightarrow$ Dinoflagellates (gonyaulax)
  responsible for red sea and red tide respectively.

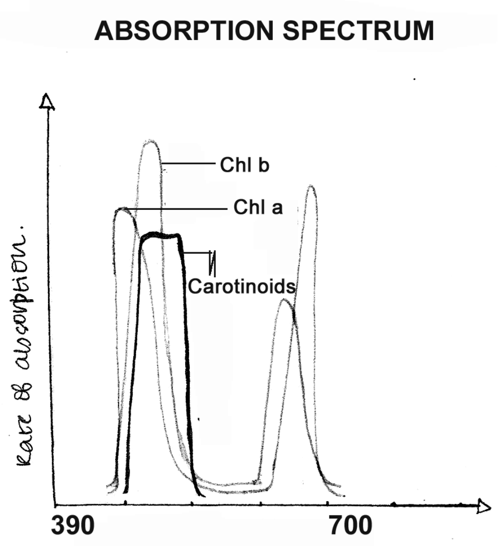
b) Phycocyanin

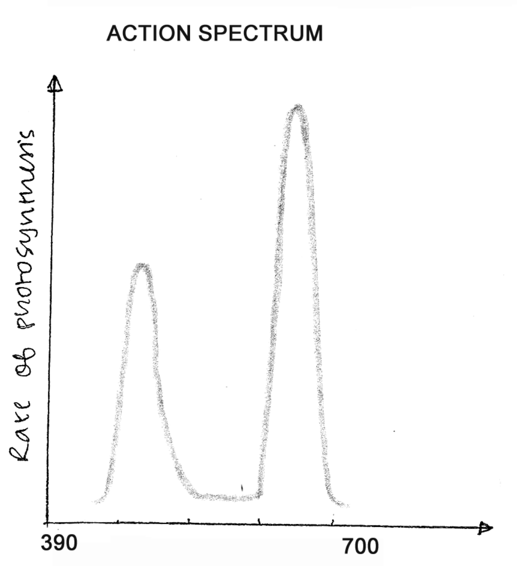
- Blue pigment
- Found predominantly in cyanobacteria
- Present in Betrachospermum, a Rhodophycean fresh water algae

c) Allophycocyanin

- Blue pigment
- Found in cyanobacteria

Note : Complementary chromatic Adaptations $\rightarrow$ Gaudukov phenomenon
$\rightarrow$ Ability to sense the quantity and quality of light in the surroundings.
(feature of Cyanobacteria and Red algae due to phycobilins)





ABSORPTION SPECTRUM	ACTION SPECTRUM
Graph showing the amount of light absorbed at each wavelength in the spectrum	Graph showing efficiency of light in carrying out photosynthesis at each wavelength.
Rate of absorption maximum blue light	Plotted by T.W. Engelman
Monochromatic light : light of single wavelength	Experimental material - Cladophora
Polychromatic light : light of different wavelength	Maximum photosynthesis occurs in polychromatic light
	Rate of photosynthesis occurs maximum in red light

* PAR : Photosynthetically active radiation. (400 - 700 nm) light most effective for photosynthesis.
* Rate of absorption maximum in blue light but rate of photosynthesis occur maximum in red light

♦ **Bell Jar Experiment**
  Demonstrated by Joseph Priestly. He proposed that plants have the ability to take up CO_2 from atmosphere and release oxygen during photosynthesis. (Plants purifying air via photosynthesis).
♦ Moll's Half leaf Experiment
  Showed that CO_2 is necessary for photosynthesis
♦ Julius Von Sachs
  Proposed that starch is the first visible and storage product of photosynthesis
♦ Jan Ingenh ousz
  Proposed the importance of sunlight in photosynthesis
♦ Connelius Van Niel
  Proposed that H_2S is the hydrogen donor of photosynthetic bacteria.

MECHANISM OF PHOTOSYNTHESIS

Involves 2 major events : Light phase / photochemical phase
: Dark phase / biosynthetic phase

1. Light Phase

♦ Reactions take place in the presence of light.
♦ Light dependent phase of photosynthesis
♦ Site : grana

Objective : Synthesis of assimilatory power (ATP/$NADPH_2$)

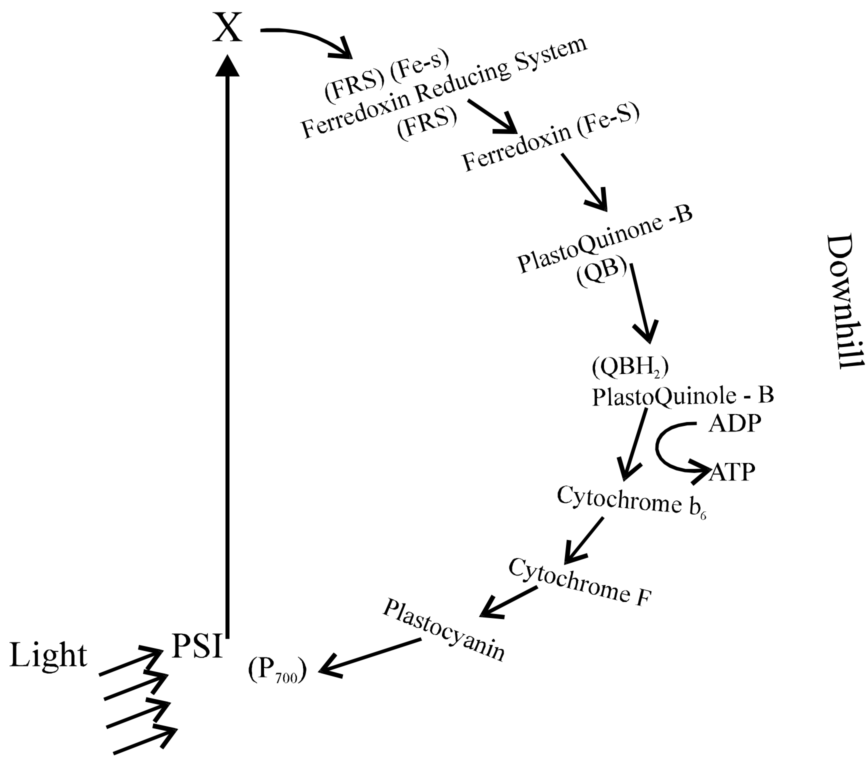
* Metabolic energy production phase

Light phase involves two major electron transport reactions

$\rightarrow$ Cyclic photo - phosphorylation

$\rightarrow$ Non cyclic photo phosphorylation

a) Cyclic Photo Phosphorylation



Step 1 : Absorption of light by antenna pigments and excitation of the electron of the pigments.

Step 2 : Light energy absorbed by antenna pigments are transferred to a reaction centre of PS I (P_{700})

Step 3 : P_{700} gets excited and high energy electrons are emitted from it. These electron with high potential energy are immediately accepted by X primary unknown electron acceptor, located towards the outer surface of thylakoid membrane.

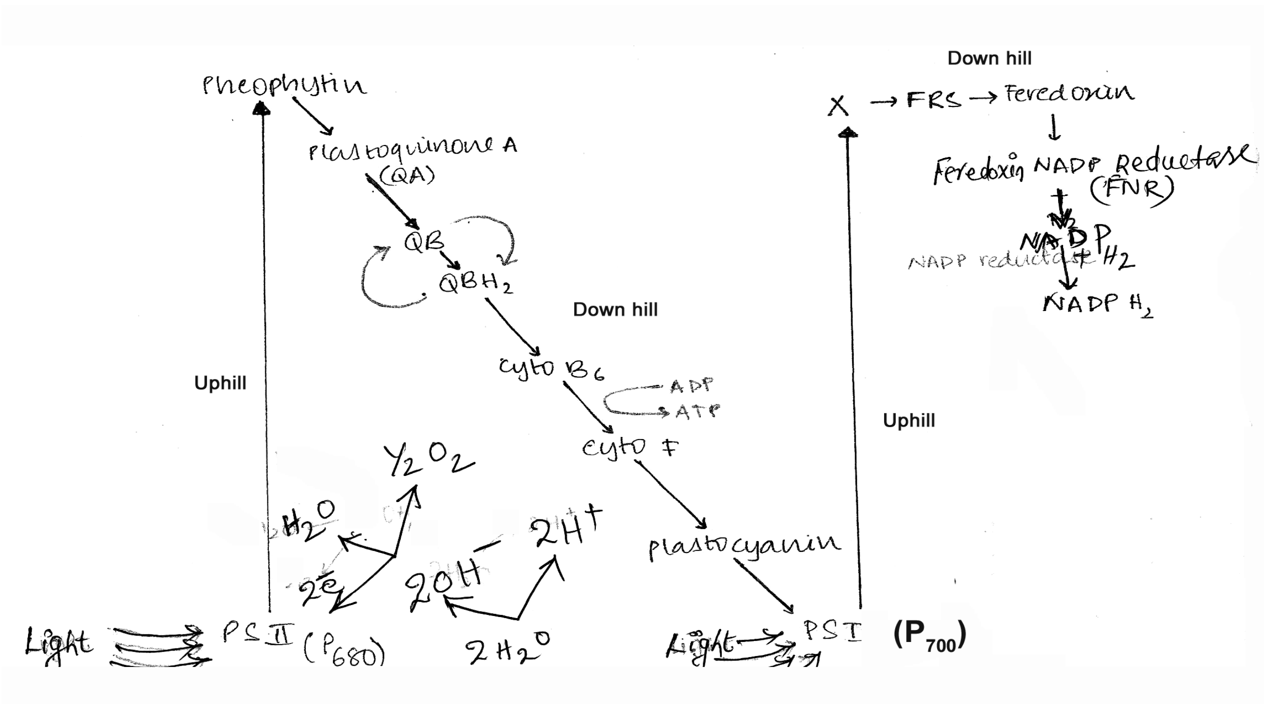
Step 4 : From x, electrons are accepted by a number of electron carriers and returns back to the original reaction centre (P_{700})

During these electron transfer, protons are pumped from stroma to lumen across the thylakoid membrane through QB and a proton gradient is established (pH in lumen low - acidic due to more protons)

Proton gradient across the membrane provides a powerful form of chemical potential energy. When proton flows spontaneously down to stroma through F_0 channel in the membrane. An amount of free energy becomes available $\rightarrow$ proton motive force (PMF)

PMF is sufficient for stimulating ATP synthase which catalysis the phosphorylation of ADP with inorganic phosphate and ATP molecules are synthesised. The phosphorylation occurs in the presence of light $\rightarrow$ Photophosphorylation.

2. Non cyclic photophosphorylation



Step 1 : All the pigments in the photosynthetic unit of PSII absorb light energy and are transferred to the neighbouring molecule and finally focussed to the reaction centre of PS II $\rightarrow$(P_{680})

Step 2 : P_{680} gets excited and high energy electron are emitted from it. These electron with high potential energy are accepted by pheophytin, located towards the outer surface of the membrane. From there, electron travels through a series of electron carriers and finally reaches the reaction centre of PS I (P_{700})

The electron deficiency PS II is compensated by splitting of water molecules in the luminal surface of grana thylakoid.

Step 3 : On absorbing light, P_{700} gets excited and emits electrons which are passed on to primary electron acceptor (x). From there electron goes through FRS to Feredoxin and is bypassed to NADP.

Step 4 : NADP combines with H^+ ions from stroma and are reduced to $NADPH_2$.

During this electron transport, protons are pumped from stroma to lumen and a proton gradient is established. When protons flow down to stroma through F_0 channel, and amount of free energy becomes available (PMF) which stimulates ATP synthase and ATP molecules are produced.

CYCLIC	NON-CYCLIC
Occurs predominatly in the stroma lamellae	Occur only in grana thylakoids
Reaction centre is P700	Both P680 and P700 are involved
Photolysis does not occur	Photolysis occur
No evolution of oxygen	Oxygen evolved
Only ATP molecules are formed	Both ATP and NADPH2 are formed
This process also occurs in photosynthetic bacteria	Common in green plants

PHOTOLYSIS OF WATER

- ♦ Light dependent splitting of water
- ♦ Mn and Cl^- ions play a major role
- ♦ D_1 and D_2 proteins are essential
- ♦ Occur in luminal side of the membrane of grana thylakoid.

HILL REACTION

- ♦ Evolution of oxygen during photosynthesis comes from water.
- ♦ Ca^{2+} ions play a major role.
- ♦ Proved by Robert Hill
- ♦ Hill reagent $\rightarrow$ Potassium Ferric cyanide

QUANTUM YEILD

- ♦ Number of oxygen molecules evolved per quantum of light (0.125)

QUANTUM REQUIREMENT

- ♦ Number of light quanta required for the evolution of one molecule of oxygen (8 photon)

PHOTOLUMINESCENCE

Ability of pigments to emit light energy.

a) Fluoroscence / kutusky effect

- ♦ Immediate emission of light
- ♦ All photosynthetic pigments having fluorescence
- ♦ Chl a having maximum fluoroscence

b) Phosphorescence

- ♦ Delayed emission of light

ETS inhibitors :

1.DCMU :Dichlorophenyl dimethyl urea
2.Monuron
3.Diuron
} Herbicides that inhibit non - cyclic ETS
Inhibit ETS from PSII to QB and O_2 evolution

4.PAN - Peroxy acetyl nitrate
5.Atrazine
} Inhibit non - cyclic ETS

6.Paraquat (viologen dye) → Inhibits cyclic ETS (PSI to Ferredoxin)

7. Dinitrophenol → Inhibits ATP synthase

Points to Remember

Red drop / Emerson's first effect :

- ♦ Sudden fall in photosynthetic yeild beyond the red region of visible spectrum which begins at 680 nm
- ♦ It was confined by Haxo and Blinks → Blink's effect

Emerson's Enhancement effect : Emersons 2nd effect

- ♦ Increase in photosynthetic activity by the combined effect of shorter and longer wavelength of red light. (655 - 700 nm)
- ♦ Red drop and Emerson's Enhancement effect proved that both PS I and PS II involved in photosynthesis. (Existence of 2 types of photosystems)
- ♦ Photophosphorylation occurs mainly due to proton motive force.
- ♦ During electron transport, ATP synthesis occurs in accordance with :
  - → Down hill movement of electrons
  - → Redox potential scale : Electron carriers are arranged in accordance with increasing reduction potential value.

* Photochemical reaction centre indirectly produce chemical energy.

CHEMIOSMOTIC HYPOTHESIS

- ♦ A hypothesis to account for ATP synthesis to accompaning electron transport in chloroplast and mitochondria.
- ♦ Proposed by Peter Mitchell
- ♦ Chemiosmosis requires :
  1. A perfect membrane : Thylakoid membrane
  2. Proton pump : Plastoquinone B
  3. Proton gradient
  4. ATP synthase

Postulates

1. Thylakoid membrane are almost impermeable to passive flow of proton
2. Electron flow occurs through this membrane resulting in the pumping of protons from stroma to lumen through a mobile H carrier ((QB) located towards the outer surface of thylakoid membrane. As a result a trans-membrane difference in proton concentration is established.

QB is not only an electron acceptor but a H carrier.

- Proton gradient across the membrane provides a powerful form of chemical potential energy. When proton flows spontaneously down to stroma through F_0 channel in the membrane, an amount of free energy becomes available.
- PMF is sufficient for stimulating ATP synthase that catalysis the phosphorylation of ADP and ATP molecules are synthesised.
- Photolysis of water is one of the reasons for generating a proton gradient in thylakoids.

Important Points

- Conversion of light energy and associated electron transport reactions of photosynthesis occurs in thylakoid membrane.
- During light phase, energy of sunlight is trapped by chlorophyll and are utilised for the synthesis of ATP and $NADPH_2$
- ATP and $NADPH_2$ produced during light phase are utilised in the second phase (dark phase) for the synthesis of carbohydrate.

  ATP and $NADPH_2$ Assimilatory powers, proposed by Arnon.
- Non cyclic electron transport does not occur in stroma lamellae due to the absence of PS II and NADP reductase enzyme.
- Pumping of proton from stroma to lumen $\rightarrow$ active transport, that requires energy.
- Flow of protons from lumen to stroma through F_0 $\rightarrow$ facilitated diffusion, does not require energy.

NADP

- Nicotinamide Adenine Dinucleotide phosphate.
- Co-enzyme $\rightarrow$ containing niacin
- Hydrogen carrier $\rightarrow$ accept both electrons and protons
- Reducing power of photosynthesis
- Found in stroma
- NADP reductase present in grana thylakoids.

PLASTOCYANIN

- Blue coloured protein
- Containing copper
- Water soluble
- Mobile
- Found in the inner surface of thylakoid membrane
- connecting plug between PS II and PS I

$$\left.\begin{array}{l}\text{FRS}\\ \rightarrow \text{FERREDOXIN}\end{array}\right\}\text{Proteins, containing ion and sulphur}$$

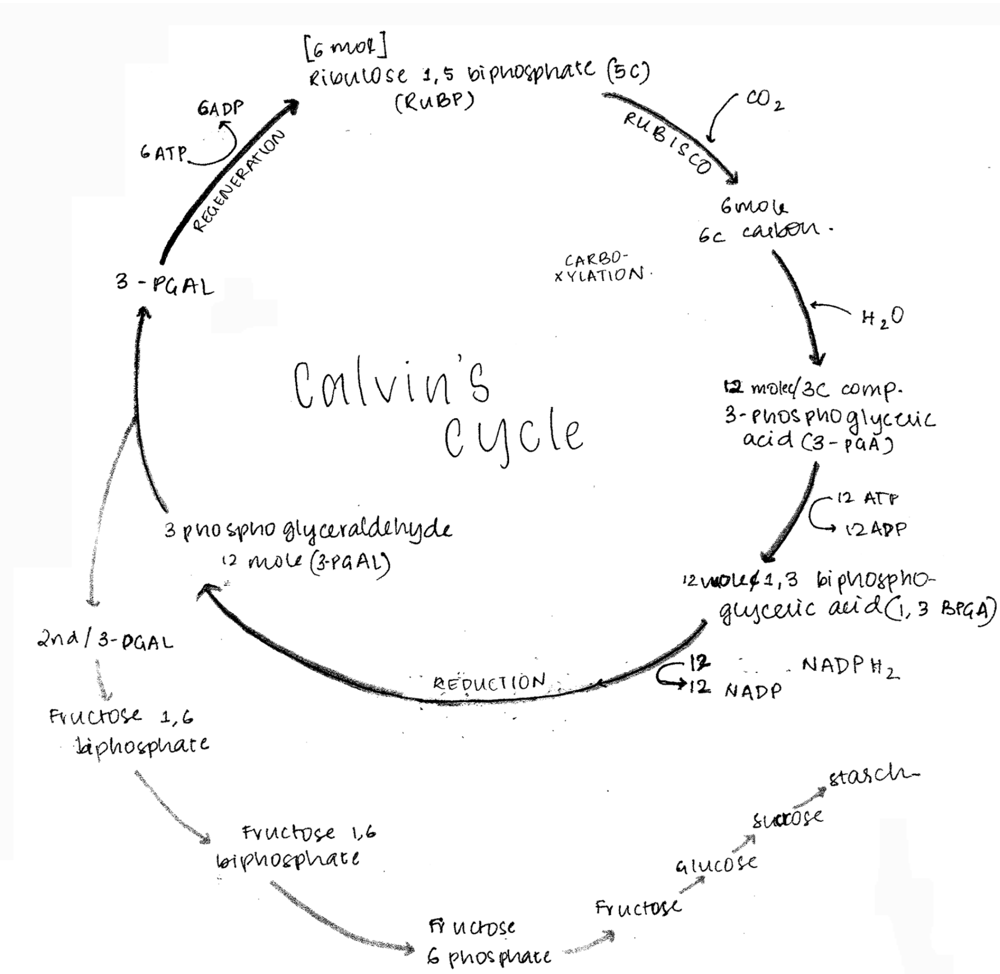
- CYTOCHROME B_6 AND F : containing iron
- Primary electron acceptor of PS I $\rightarrow$ FeS protein
- Oxysomes are present in the membrane of both stroma lamellae and grana thylakoids.

2-Dark Phase

- Photosynthetic carbon dioxide fixation / photosynthetic carbon reduction cycle.
- The reactions takes place in the presence or absence of light
- Light independent phase of photosynthesis
- Sight $\rightarrow$ stroma
- Objective : synthesis of carbohydrate
- First discovered by F. F. Blackman $\rightarrow$ Blackman's Reaction
- The path of carbon in this process was first traced by Melvin Calvin, an American scientist for which he got nobel prize. After that, these chemical reactions are known by his name $\rightarrow$ Calvin cycle.
- Experimental method - Radio active isotope technique [C^{14}]
- Experimental material - chlorella
- Fixation of CO_2 at the level of carbohydrate can be considered to occur in 4 distinct phases.

$$\left.\begin{array}{l}1.\text{Carboxilation}\\2.\text{Reduction / glycogenic Reversae}\\3.\text{Regeneration of RUBP}\end{array}\right\}\text{Calvine cycle} - \text{It involves 3 major events}$$

4. Product synthesis phase



Universal Photosynthetic Pathway

- Autocatalytic process,

  In one side synthesise carbohydrates and on the other side regenerate 5 carbon compound RUBP.

  1° CO_2 acceptor : RUBP

  Ist stable product : 3PGA $\rightarrow$ Hence the process is considered as C_3 cycle.

  1° carboxilation enzyme $\rightarrow$ RUBISCO (Ribulose biphosphate carboxylase oxygenase)

RUBISCO

- Found in stroma
- Most abundant enzyme in the biosphere
- 16% of total protein in chloroplast
- light regulated enzyme - active only when light is available
- Functional at alkaline pH (pH = 8)
- Mg is the major stimulator
- Possess high Km value (low efficiency)
- **First stable product - 3PGA**
- key compound in Calvin cycle - 3PGA
- last stage of calvin cycle - regeneration of RUBP

$\rightarrow$ Essential requirements for the synthesis of 1 molecule of glucose.

- 6 Calvins cycle
- 6 CO_2
- 6 RUBP
- 18 ATP
- 12 $NADPH_2$

$\therefore$ Every calvin cycle requires 3 ATP and 2 $NADPH_2$

1. CARBOXILATION

- 6 molecules of RUBP are carboxylated to form 6 molecules of 6 carbon compounds. (Catalysed by RUBISCO)
- 6 carbon compound are hydrolyse to form 12 molecules of 3 PGA

2. REDUCTION

- 12 molecules of 3 PGA are phosphorylated to form 12 molecules of 1, 3 biphospho glyceric acid.
- 12 molecules of BPGA are reduced to 12 molecules of 3 PGAL with the expenditure of 12 $NADPH_2$

3. REGENERATION

- 10 molecules of 3 PGAL are used for the regeneration of 6 molecules of RUBP with the expenditure of 6 ATP.

4. PRODUCT SYNTHESIS PHASE

- 2 molecules of 3 PGAL are converted into 1 molecule of fructose 1, 6 biphosphate.
- They are phosphorylated to form fructose and fructose is converted to glucose

  Glucose $\rightarrow$ prepared form

  Sucrose $\rightarrow$ translocation form

Starch $\rightarrow$ stored form

The chemical reactions of calvins cycle does not require light. But most of the enzymes including RUBISCO are light regulated. So dark reactions (calvin cycle) only occurs during day time.

PHOTORESPIRATION

C_2 pathway / glycolate pathway / photosynthetic carbon oxidation cycle (PCO cycle)

The processes involves the intake of oxygen and release of carbon dioxide in the presence of light.

- Discovered by Decker and Tio
- Sometimes oxygen competes with carbon dioxide for the active site of RUBISCO, then RUBISCO catalysis the condensation of oxygen with RUBP instead of carboxylation.

The major factors stimulating the oxygenation of RuBP.

$\rightarrow$ Low CO_2 level

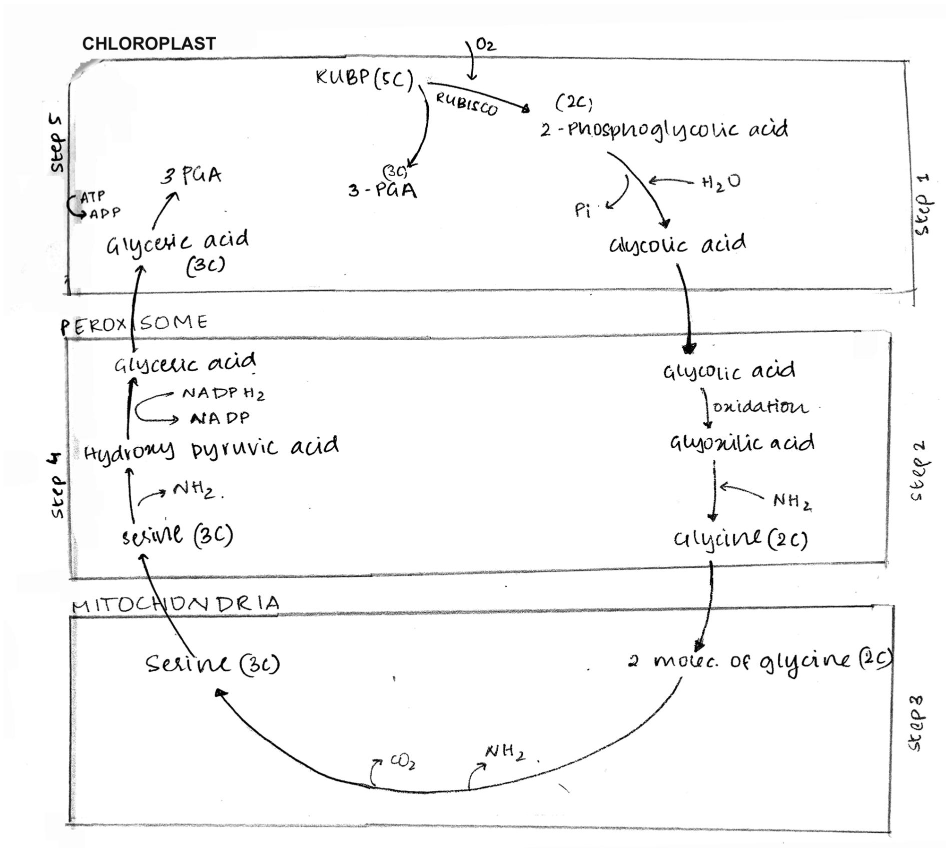
$\rightarrow$ High oxygen level

$\rightarrow$ Continuous strong light intensity

3 cell organelles are involved in it.

- Chloroplast
- Peroxisome
- Mitochondria

- Photorespiration occurs only in C_3 plants.
  - First stable product $\rightarrow$ 2 phospho glycolic acid (2C)
  - Hence, the process is considered as C_2 pathway
  - Substrate of the pathway $\rightarrow$ Glycolic acid : Hence the process is also said to be glycolate pathway.
  - It is a metabolic adjacent to Calvin's cycle in C_3 plants because it is a gate way of C_3 plants which helps to enter into Calvin's cycle when the conditions are unfavourable for carboxylation.



- In this pathway neither synthesis of sugar nor ATP (ATP and $NADPH_2$ are consumed in the pathway - an expensive process).
- 3-PGA is the connecting link between photorespiration and Calvin's cycle in C_3 plants.
- 2 molecules of glycine are required for the evolution of one molecule of 1 molecule CO_2
- Amination occurs in peroxisome (glycoxylic acid).
- Deamination occurs in mitochondria and peroxisome
- Decarboxylation occurs in mitochondria.

C_4 PHOTOSYNTHESIS

- Co-operative photosynthesis / Hatch - Slack pathway / Dicarboxylic acid cycle.
- It discovered by Kortschak and Hartt
- The details regarding the pathway were first discovered by Hal Hatch and Roger Slack

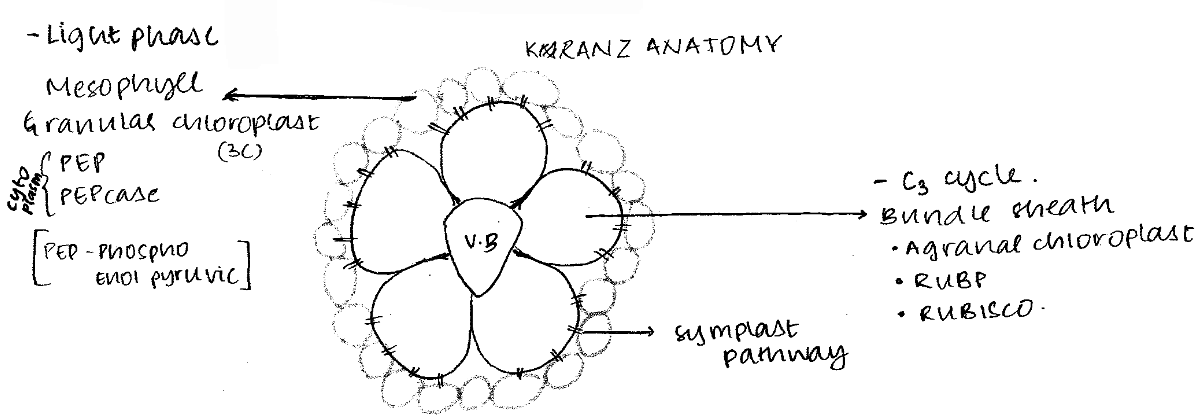
Example of C_4 plants :

Amaranthus spinosa - dicot

Atriplex Panicum Sugarcane Maize Bejra (pearl millets) Sorghum	Monocot

They have developed a special mechanism for the synthesis of carbohydrate.

Special features of C_4 plants.



2 types of photosynthetic cells.

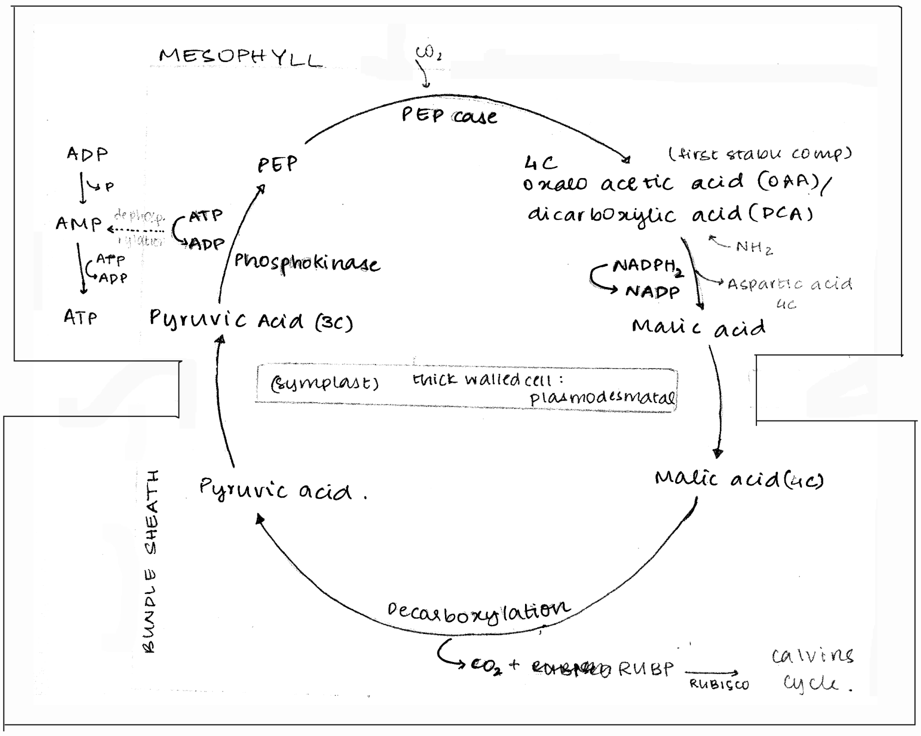
$$\left.\begin{array}{l}\text{Mesophyll}\\ \text{Bundle sheath}\end{array}\right\}\text{connected together by plasmodesmata} - \text{symplast}$$

- ♦ Circular arrangement of bundle sheath, around the vascular bundle - Kranz Anatomy ; wreath like arrangement.
- ♦ Exhibits chloroplast dimorphism.

Note :

- ♦ C_4 plants can tolerate high temperature and show response to high light intensity.
- ♦ Concentric arrangement of mesophyll leads to minimum surface area so that the effect of high light intensity can be overcome.

MESOPHYLL	BUNDLE SHEATH
thin walled	thick walled
arranged with or without intercellular spaces	arranged compactly without intercellular spaces
Granal chloroplast (Chloroplast with grana)	Agranal chloroplast (without grana)
less number of chloroplast	large number of chloroplast
both PEP and PEPcase are present in the cytoplasm	RUBP and RUBISCO are present in the chloroplast
Light phase and primary carboxylation occurs	Calvins cycle occurs (Carbohydrate synthesis)
Light phase - Chloroplast	Imprevious to gaseous exchange
Primary carboxylation occur in cytoplasm	Arranged in several layers around the vascular bundles



- 6 C_4 cycles and 6 C_3 cycles are required to produce 1 glucose in all C_4 plants.
  C_3 cycle $\rightarrow$ RUBISCO C_4 cycle $\rightarrow$ PEP case

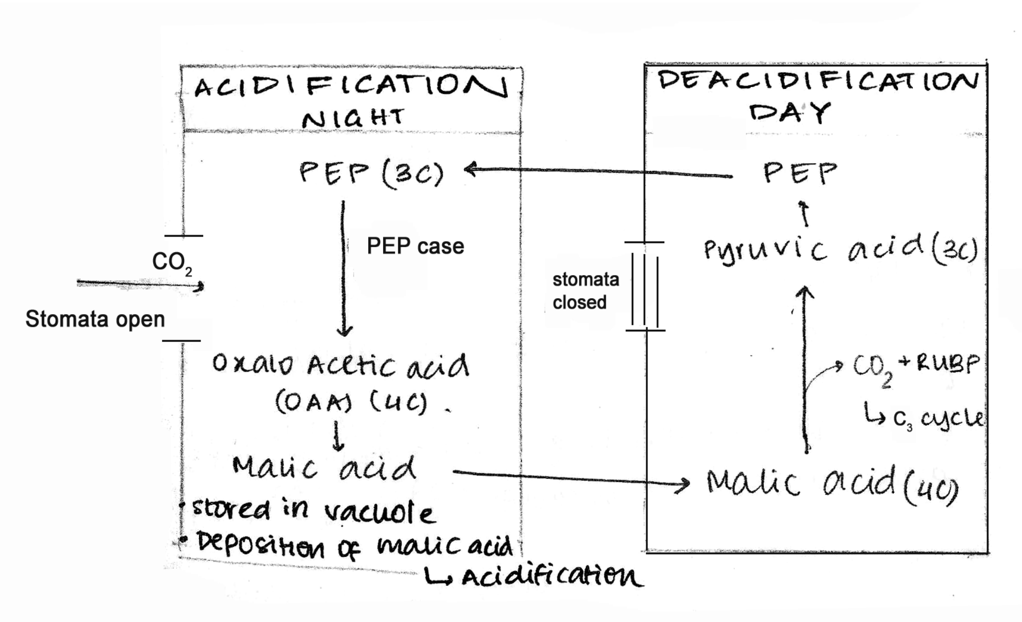
  $1C_4$ cycle $\rightarrow$ 2 ATP $\left.\begin{array}{l} 6C_4\text{cycle} \rightarrow 12\text{ATP} \\ 6C_3\text{cycle} \rightarrow 18\text{ATP} \end{array}\right\} 30\text{ATP metabolically expensive}$

- The aim of C_4 photosynthesis is to build up high CO_2 concentration near RUBISCO in the bundle sheath. It leads on carboxylation of RUBP and thus prevent photorespiration.
- Both C_4 cycle and C_3 cycles are involved but RUBISCO functions only in C_3 cycle.
- $6C_4$ cycles and 6 C_3 cycles are essential for the synthesis of 1 molecule of glucose.
- 30 ATP molecules are essential (12 ATP in $6C_4$ cycle + 18 ATP in $6C_3$ cycles)
  $\therefore$ Every C_4 cycle requires 2 ATP due to phosphodikinase activity
- Primary CO_2 acceptor (PEP)
- Primary carboxylation enzyme - PEP case
- I[st] stable product - oxalo acetic acid (4C / Dicarboxylic acid) - Hence the process is considered as dicarboxylic acid cycle or C_4 pathway.
- C_4 plants are more efficient than C_3 plants for the synthesis of glucose.
  $\rightarrow$ Primary CO_2 fixation is mediated via PEPcase possess low km value (highly efficient). So they have more affinity for CO_2.

C_3 PLANTS (Tomato, bell pepper/capsicum)	C_4 PLANTS (Sorghnum, bajra)
only one type of cells are involved in CO_2 fixation - Mesophyll	Types of cells involved (2) : Mesophyll and bundle sheath
1^o carboxylation occur in mesophyll	1^o carboxylation occur in mesophyll
Calvin cycle occur in mesophyll	Calvin cycle occurs in bundle sheath
1^o CO_2 acceptor is RUBP (5C)	1^o CO_2 acceptor is PEP (3C)
1^o carboxylation enzymes RUBISCO	1^o carboxylation enzyme : PEPcase
I^{st} stable product : 3PGA(3C)	I^{st} stable product : OAA (4C)
RUBISCO present in mesophyll	RUBISCO present in bundle sheath
Normal leaf anatomy	Kranz anatomy
Only in C_3 cycle present	Both C_3 and C_4 cycles are involved
Photorespiration occur at low CO_2 level	No photorespiration
Photorespiration occur in continuous strong light intensity	Not affected
Photorespiration occur in continuous high temperature	Not affected
Optimum temperature for photosynthesis [20^oC - 30^oC]	Optimum temperature 30^oC - 40^oC

Crassulacean Acid Metabolism [CAM]

- Nocturnal photosynthetic activity
- Special adaptive photosynthesis occur in xerophytes / succulents
- Plants can live in xeric habitat (dry condition)
  eg. Pineapple, Opuntia, Agave, Kalenchoe
- I^{st} discovered in Bryophyllum, a member of Crassulaceae
- Scotoactive stomata - opens in the night



- Both PEP case and RUBISCO are found at the same mesophyll cell.
- Acidification occur at night due to deposition of malic acid.
- Deacidification occurs during day time due to decarboxylation of malic acid.
- Primary carboxylation occur at night
- Calvins cycle occur in day time
- 1^o CO_2 acceptor : PEP
- Primary carboxylation enzyme : PEP case
- Mechanism is similar to C_4 pathway
- Major stimulator of PEPcase : Magnesium (Mg)

FACTORS AFFECTING PHOTOSYNTHESIS

1. Law of Limiting Factor :

- Proposed by F.F. Blackman (1905)
- When a process is conditioned as to its rapidly by a number of separate factor, the rate of the process is limited by the pace of the slowest factors.

A. External Factors :

a) Light

- Inside the leaf, chloroplast occur in mesophyll along their wall for easy diffusion of gases and receiving optimum quantity of incident light.
- Chloroplast moves along actin filament (microfilament) in the cytoplasm and Ca^{2+} regulate their movement.

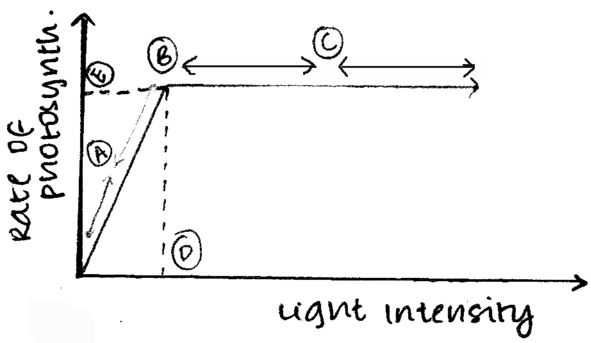
- Chloroplast arranged parallel to the cell wall/ perpendicular to incident light - For maximum absorption (intermittent light in the atmosphere).
- Except sciophyte (shade loving plants) and plants of dense forests light is rarely a limiting factor in nature.

Note : In twilight (twice a day-morning and evening), rate of photosynthesis and rate of respiration will be 1:1

- It occurs due to light - light compensation point.
- Moonlight is trapped by marine red algae due to phycoerythrin

i) Light intensity

- Rate of photosynthesis is dependent on light intensity
- Total photosynthesis is dependent on light intensity
- Intermittent light / Flashing light is most effective for photosynthesis
- Increase in incident light beyond a point causes breakdown of chlorophyll and decreases rate of photosynthesis



A $\rightarrow$ light intensity

B $\rightarrow$ Some factors other than light intensity becoming limiting factor

C $\rightarrow$ Light is no longer the limiting factor

D $\rightarrow$ Saturation point of light intensity

E $\rightarrow$ Maximum rate of photosynthesis

ii) Light Quality

- Refers to wavelength
- PAR (400 - 700 nm) best quality light for efficient synthesis of sugar
- % of PAR - 50%

  Among them, below 10% are utilised for photosynthesis
- Rate of photosynthesis occur maximum in red light, followed by blue
- Green light is least effective

iii) Light Duration

- Light duration does not affect the rate of photosynthesis
- Rate of photosynthesis is independent of duration of light
- Light duration affect total photosynthesis

iv) Carbon Dioxide

- Major limiting factor of photosynthesis
- % of CO_2 in atmosphere : 0.03%
- In terrestrial conditions, CO_2 usually get act main determining factor of photosynthesis because CO_2 is available at sub-optimal level.
- In C_3 plants CO_2 saturation at about 450 m/L
- In C_4 plants CO_2 saturation of abut 360 m/L
- Photosynthesis in C_4 plants are relatively less limited by atmospheric CO_2 level because primary fixation of CO_2 is mediated by PEPcase
- Productivity of C_4 plants does not increase when CO_2 increases, because the present level of atmospheric CO_2 is generally not limiting factor for C_4 plants.
- Very high CO_2 conc. (0.09 - 1%) stimulate abscisic acid (ABA) and therefore stomata to close and hence reduces CO_2 availability.
- **CO_2 compensation point :** CO_2 concentration at which CO_2 fixation in photosynthesis is equal to the volume of CO_2 released in respiration.

  High CO_2 compensation point $\rightarrow$ C_3 plant

  Low CO_2 compensation point $\rightarrow$ C_4 plant

3. Temperature

- C_4 plants respond to higher temperature and show higher rate of photosynthesis
- Tropical plants (C_4) have higher temperature optimum than the plants adapted to temperature climate
- In C_3 plants at continuous high temperature, rate of photosynthesis decreases due to denaturation of enzymes.
- Dark reactions are more affected by temperature as compared to light reactions
- Some coniferous gymnosperms can photosynthesis even at -35^{o}C
- Oscillatoria (Cyanobacteria) photosynthesis occur at 70^{o}C - 80^{o}C

4. Water

- Percentage of water used for photosynthesis - 1%
- Water stress causes stomata to close and hence reduce CO_2 availability and therefore decreases rate of photosynthesis.

Note : Warburg Effect

Reduction of photosynthesis due to high concentration of O_2

B. INTERNAL FACTORS

- Chlorophyll content
- Leaf anatomy
- Leaf age

Points to Remember

- PEPcase enzyme present in CAM and C_4 plants and also in C_3. In C_3 plants, it is present in the guard cell.