PHOTOSYNTHESIS

HISTORY OF PHOTOSYNTHESIS

- **Aristotle and Theophrastus (320 BC) : -** State that plants absorb all food matter from soil (Humus theory).
- **Van Helmont (1648) : -** By wieghing the Willow plant, concluded that plant take up their for mostly from soil water
- **J. Woodbard (19699) : -** Besides water, soil also increases the weight of plant.
  Stephen Hales (1727) : - Recognised the importance of air (CO_2) ad light for photosynthesis (nourishment) in plant. He in considered as discover of photosynthesis and **"Father of plant physiology:**
- **J. Priestely (1772) : -** He carried out very interseting **experiment on Bell jar,** Rat, Pudina & Candle. he came to conclude theat plants purify air (burning of candles) and gaseous exchange occurs during photosynthesis. (Phlogito $\Rightarrow$ Bad air from candles)
- **jan Ingenhousz (1779) : -** He explained the importance of light and green colour and also suggested the O_2 releases in the presence of light by green parts.
- **Senebiar (1782) : -** Green plants absorb CO_2 from atmosphere and when the concentration of CO_2 increases the rate o O_2 evolution also increases.
- **N.De-Saussure (1804)-** Clarified that releases O_2 is equal to the absorbed CO_2. He realised the significance of H_2O in this process. De-Saussure stated that O_2 comes from CO_2 during photosynthesis. (Later on it was disproved by Van Neil)
- **Pallatiar & Caventou (1818) :** They named green pigment as Chlorophyll and isolated the chlorophyll with the help of alcohol.
- **Mayer (1845) :** Green plants convert solar energy into chemical (potential) energy in the form of organic substance He gave law of conservation of energy. Formation of organic matter recognised by Mayer.
- **Leibig (1845) :** Organic matter are derived from CO_2 and H_2O. during the process of photosynthesis.
- **J.V. Sachs (1862) :** Recognised the relation among photosynthesis, chloroplast and starch. First visible product of photosynthesis starch. Founder of modern concept of photosynthesis. Some people consider Sachs as fatter of plant physiology. Three cardinal point concept wall also given by him.
- **Willstatr, Stall Fisher :** Chemistry, structure and properties of Chl-a, and noble prize winner.
- **F.F. Blackman (1905) : Dark reaction** associated with **height reaction** in photosynthesis and law of limiting factors.
- **Warburg (1920) : Intermittent** or **flash light experiment** on Chlorella and proved that dark reaction exists in photosynthesis.
- **Emerson and Arnold (1932)** : Concept of two pigment system (photo system) in light reaction. **Red drop & Emerson enhancement effect.**
- **Van Niel - O_2 releases from water** and O_2 of glucose cosmes from CO_2.

$$6CO_2 + 12\,H_2S \xrightarrow{\text{Bacteria}} C_6H_{12}O_6 + 12S + 6H_2O$$

- **Robert Hill & Bendal (1937) :** Detailed study of light reaction in isolated chloroplast of Stellaria.
- **Photolysis of H_2O** is the chief role of chloroplast and evolution of O_2 only in the presence of suitable aceptor, from water in photosynthesis. (Hill - reaction)
- **Ruben, Hassi & Kamen (1941) :** Used O^{18} to experimentally show that O_2 in photosynthesis released from water.

$$6CO_2^{16} + 12H_2O^{18} \xrightarrow[Chlorophyll]{Light} C_6H_{12}O_6^{16} + 6H_2O + 6O_2^{18}$$

- **Arnon :** ATP formation is presence of light (photophosphorylation) and cyclic and non cyclic electron transport system.
  M. Calving and Benson (1954) : Biochemical cyclic pathway of dark reaction and recognised PGA is Ist stable product in dark reaction. (It is formed from unstable 6C Keto Acid.)
  - C_2 - cycle or Calvin - Benson - cycle discovered.
  - Chromatography and Radioisotopy (C_{14}) techniques used in Chlorella and Scenedesmus algae. (Nobel Prize 1960).
- **Arnon , Allen & Whitley (1954) :** CO_2 fixation demonstrated in isolated chloroplast by $C^{14}O_2$ isotope.
- **Hatch & Slack (1967) :** C_4 pathway dicarboxylic acid cycle (DCA cycle) in sugarcane and maize. Ist stable product is oxaloacetic acid (OAA 4C).
- **Moll :** CO_2 is essential for photosynthesis by **half leaf experiment.**
- **Govindji & Robinowitch :** Studied ultrastructue of pigment system in detail.
- **Kok & Clyaton :** Chl - a, P- 700 discovered
- **Businganult : Photosynthetic Quoteint (PQ)** or **Assimilaory coefficient** $= \frac{O_2}{CO_2} = 1$
- **Park & Biggins:** Photosynthetic units as **Quantasome** in chloroplast.
- **Huber Michel and Dissenhofer :** Crytalization & X-ray crystallography of reaction center in Rhodobacter (Nobel-1998).

INTRODUCTION

"Photosynthesis is a photo-biochemical process **(anabolic & endergonic)** in which organic compound (carbohydrates) are synthesised from the inorganic **raw material (H_2O & CO_2)** in presence of light & pigments. O_2 is evolved as a by product"/

- **Light energy is conversed into chemical energy by Photosynthesis.**

$$6CO_2 + 12H_2O \xrightarrow[\text{light}]{\text{Pigment}} C_6H_{12}O_6 + 6O_2 \uparrow + 6H_2O$$

Reduction/datk reaction.

oxidation/light reaction

- 90% of total Photosynthesis is carried out by aquatic plants (85% algae) & 10% by land plants.
- First true & oxygenic Photosynthesis started in **cyanobacteria.** (BGA).
- In the **Cuscuta** & **Fungi** Photosynthesis is absent. **Euglena** is Photosynthetic organism & is link between animal & plants.
- Roots of **Tinospora** & **Trapa** are assimilatory or Photosynthetic.
- **Absorption spectrum** of Photosynthesis is **blue** & **red** light. (maximum absorbed part of spectrum)
- Action spectrum of Photosynthesis in **red** & **blue** light (most effective in reaction)
- Rate of Photosynthesis is higher in red wavelength of light, but **highest in white light** (full spectrum), than monochromatic light

IMPORTANT SCEINTIFIC CONTRIBUTION :

- According to **Van Neil,** oxygen comes from water in Photosynthesis.

$$6CO_2 + 12H_2S \longrightarrow C_6H_{12}O_6 + 12S + 6H_2O$$

- **Ruben, Hassid** and **Kamen (1941):-** Used **O^{18}** to show experimentally that O_2 in Photosynthesis comes from water.

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

Existence of two steps in Photosynthesis -

- **Blackman** discovered drk reaction (By study of Q_{10} value or temperature coefficient).
  Calving and **Benson** gave cyclic pathway for this, thus dark reaction is called as **calvin cycle** OR C_3-cycle

- O_{10} (Temperature coefficient) for **light reaction is one,** while Q_{10} for **dark reaction is between 2-3** (By Vont Hoff).

- Q_{10} means the doubling of rate of reaction whic involves chemicals, o 10^0C rise in temperature in it' optimum range.

- Experimental evidences for Blackman findings were given by Warburg 1920. He carried out **intermittent light experiment on Chlorella.** (by using flash light)

- The rate of Photosynthesis has been fond greater in **intermittent light** (i.e. light given after intervals of dark perids) than in continuous light.

- This is due to the fact that light reactions are after than the dark reaction.
  In continuous light product of light reactions (ATP and $NADPH_2$) are no consumed at the same rate as in subsequent dark reaction. Thu dark reaction is rate limiting step of Photosynthesis.

- Photosynthesis - (i) Light react^n/Holl react^n (i) Dark reaction/Blackman react.

- **Hill Reaction -** Experiment on isolated chloroplast **(Stelaria** plant) study of light reaction, which is called as **Hill Reaction.**
  O_2 gas liberated fro **photolysis of H_2O,** only in the presence of suitable e^- acceptor. (DCPIP (Dichlorophenon Indophenol - a dye), **ferricyanide, $NADP^+$ - Hill reagents)**

$$\frac{1}{2}O_2 \leftarrow \overset{\text{Light}}{H_2O} \begin{matrix} \nearrow 2H^+ \\ \searrow 2e^- \end{matrix} + NADP^+ \longrightarrow NADPH_2$$

- **Emerson & Arnold -** worked on **Chlorella** and gave the concept of **two photosystem** or two pigment systems.
  When they gave monochromatic light, longer than 680 nm wavelength, then quantum yield is suddenly dropped down, this event is called as **red drop.**

- When Emerson gave light, shorted and grater than 680 nm (combined light) then Photosynthetic, activity increases, this is called as **Emerson effect** or **enhancement effect.**
  (i) 680 nm $\uparrow \Rightarrow$ PS - I (cyclic process) **red drop appears.**
  (ii) 680 nm $\downarrow$ + 680 $\uparrow$ nm (Mixed light) $\Rightarrow$ Both cyclic & non cyclic operates. **(Emerson effect)**

Quantum requirement -

The number of light Quanta or photons requires for the evolution of 1 mol. of O_2 in Photosynthesis = 8

Quantum Yield -

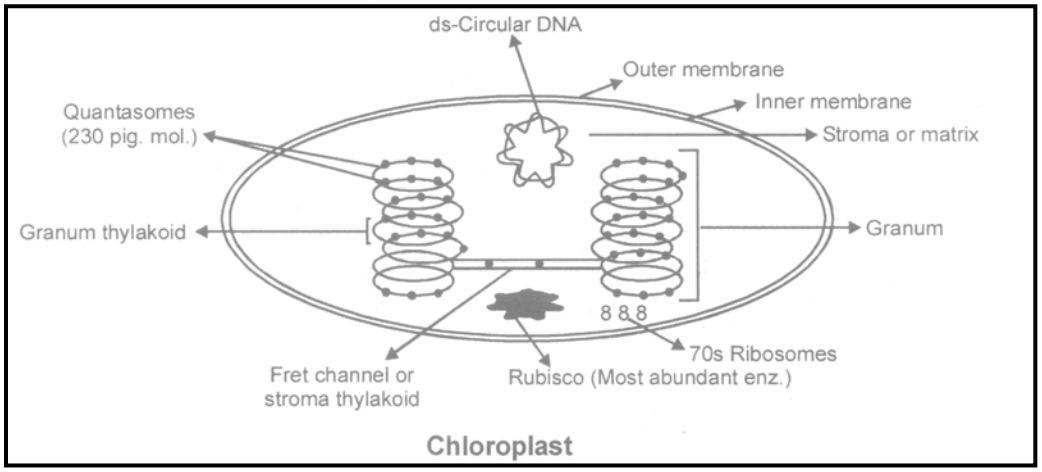
The number of oxygen molecule evolved by one quantum of light in Photosynthesis is called as **Quantum yield.** Emerson calculated that the quantum requirement in 8. Hence the quantum yield is 0.125 or 12.5%)

- **Arnon's experiment (Chlorella) -**

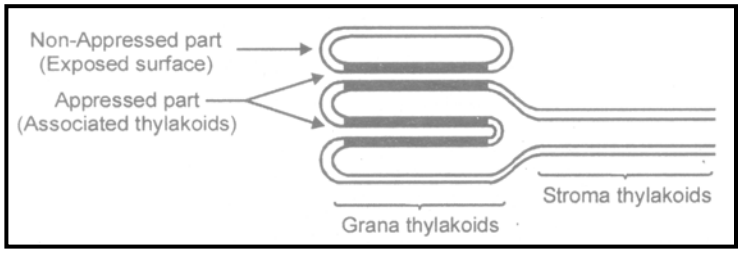
  Discovered cyclic and non-cylcic Photophosphorylation (ADP + ip $\xrightarrow[\text{Chl.}]{\text{light}}$ ATP).

  (E.T.S. in Photosynthesis was proposed by Arnon.)

CHLOROPLAST AND PIGMENTS



Photosynthetic pigments :-

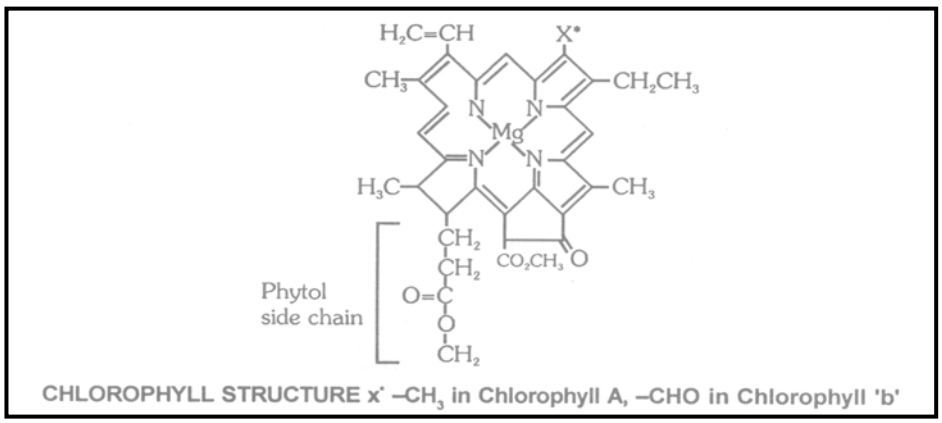


- Many pigment present in photosynthetic cells. **PSU** (Photosynthetic units) presents on thylakoid membrane, are made up of 230-40 molecules of various pigments, called **Quantasome** by **Park** & **Biggins.**
- The PS II is located in the **appressed region** of granal thylakooids and PS I in **non appreassed** region of grana and stroma thylakoids.
- PS I located - on both granum & intergrnum (Stroma thylakoid), **(P-700, 680 nm ↑ Cyclic ETS).**
- PS II located - on only granum **(P- 680, 680 nm ↓ non cyclic ETS).**
- **Chlorophyll - a** $C_{55}H_{72}O_5N_4Mg$ → CH_3 grp. at IIIrd C of IInd pyrrole ring.
- **Chlorophyll - b** $C_{55}H_{70}O_6N_4Mg$ → CHO group at IIIrd C of IInd pyrrole.
- Chlorophylls are magnesium porphyrin compounds. Porphyrin ring consists of four-pyrrole rings (Tetrapyroole).
- Chlorophyll molecule ahs a Mg-porphyrin head and alcoholic phytol tail. Head is hydrophilic and phytol tail is ipophilic (hydrophobic).
- Phytol tail is alcoholic with one double bond. Phytol part embedded in lipid layer.
- Chl - a and **carotenes** are universal pigment, which are found in all O_2 liberating cells.
- Chlorophlls are soluble only in organic solvents like ketons, ethers etc.
  Stroma lamellae/stroma thylakoids lck PS II and enxyme NADP reductase.
  In paper chromatography/chromatgram -
  Chlorphyll 'b' as - yellow green/grans green.
  Xnthopyll as - yellow
  Carotenoids as - Yellow to yellow - orange

Chlorophyll synthesis :

- Succinyl CoA + Glycine → Protochlorophyll (Protochlorophyllide $\xrightarrow[2H]{\text{Light}}$ Chlorophyll.

Light for chlorophyll synthesis is required only in angiosperms (exception **Nelumbium** and **Citrus)**



CHLOROPHYLL STRUCTURE x˙ –CH_3 in Chlorophyll A, –CHO in Chlorophyll 'b'

DISTRIBUTION & LIGHT ABSORPTION OF PIGMENTS

Pigments	Formula	Distribution	Absorption (mμ)
Chlorophylls →			
Chl - a	$C_{55}H_{72}O_5N_4Mg$	**All green plants.**	435, 670, 680 (Several forms)
Chl.- b	$C_{55}H_{70}O_6N_4Mg$	All green plans (except BGA Red, brown and diatoms algae)	453, 480, 650
Chl.- c	$C_{35}H_{32}O_6N_4Mg$	Brown algae and diatoms	645
Chl.- d	$C_{54}H_{70}O_6N_4Mg$	Red Algae (Rhdophyceae)	740
Chl.- e		Xantophyta (**Tribonema** & **Vaucheria** Zoospoores) Purple & green bacteria	
Bacterio Chl. -a	$C_{55}H_{74}O_6N_4Mg$	**Purple bacteria**	800,850890
Bacterio Chl. -b	$C_{55}H_{74}O_6N_4Mg$	**(Rhodopseudomonas)**	1017
Bateriovіridin (Chlorobium chlorophyll)		Greenbacteria**(Chlorobium)**	750,760
Carotenoids →			
Carotenes →			
α **-** Carotene	$C_{40}H_{56}$	Red, green algae & All green plants	450, 470
β -Cartone	$C_{40}H_{56}$	In all green plants	450, 480
γ -carotene		Green bacteria	
Xanthophylls/Carotenenols →			
Luteole	$C_{40}H_{56}O_2$	Red, Green algae, all plants	425, 475
Violaxanthin	$C_{40}H_{56}O_2$	Green leaves	425, 450, 475
Fucoxanthin	$C_{40}H_{56}O_3$	In Brown algae	
Phycobilins →			
Phycocynanin		**BGA** (mainly), red algae	618
Phyceorythrin		**Red algae** (mainly), BGA	490, 576
Allophycocyanin			

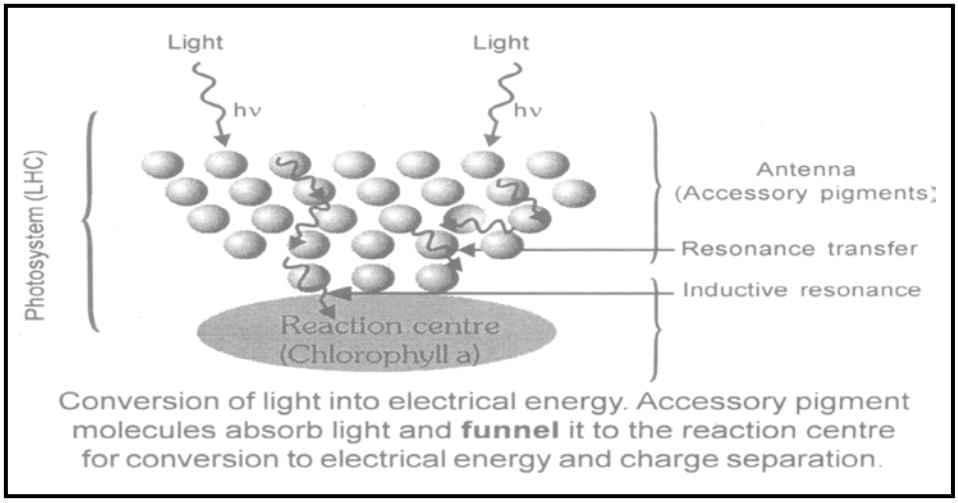
400 & 700 nm light is used in Photosynthesis also known as **PAR (Photosynthetic active radiation)**

MECHANISM OF PHOTOSYNTHESIS

[A] Light reaction/Hill reaction/Photochemical reaction/Generation of assimilatory powers ($NADPH_2$ + ATPs) Photophase.

- During the light reaction, the primary function of the two pigment systems/photosystems is interact with each other to trap light energy and convert in into the chemical energy (ATP). These reactions are cyclic and non cyclic types.

- Antenna or accessory pigments receive radiant energy and transfer it among themselves. This transfer of energy is known as **resonance transfer**. Then antenna molecules excited and transfer their energy to the chlorophyll 'a' molecules of **reaction centre.**

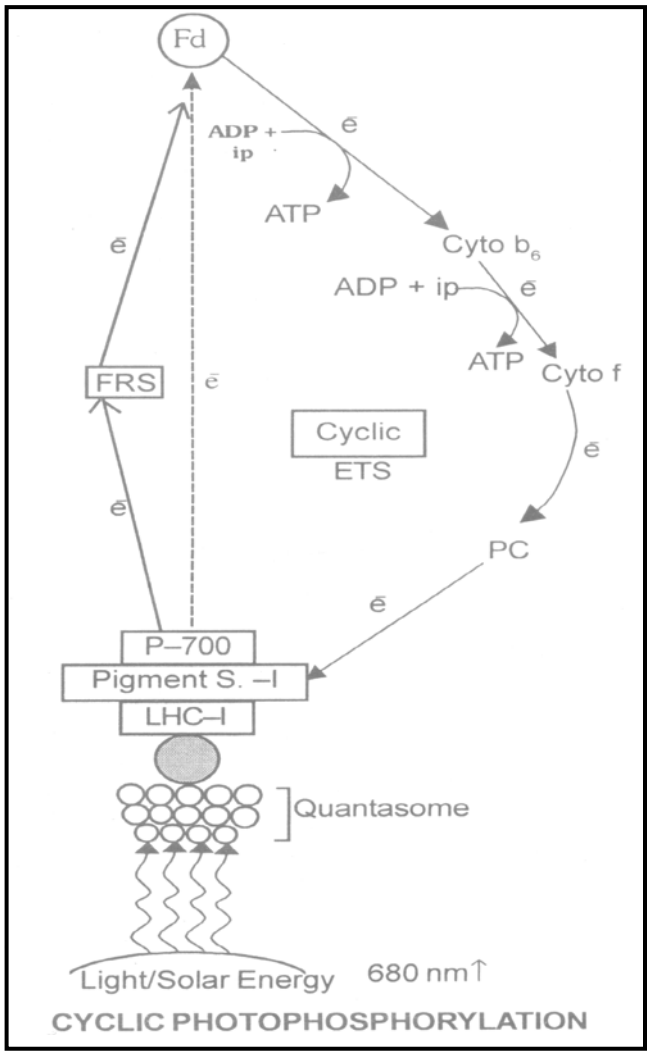


Conversion of light into electrical energy. Accessory pigment molecules absorb light and **funnel** it to the reaction centre for conversion to electrical energy and charge separation.

it is known as **inductive resonance.** Finally chl. 'a' molecules converts **light energy into electrical energy** by bringing about **electric charge separation.**

(I) Cyclic ETC and Photophosphorylation.

- In cyclic ETS, only PS-I (LH-I) works which consists of Chl- 'a' 670, Chl-a683, Chl 'a' -695, carotenoids, some molecules of chl 'a'& reaction centre-Chl-'a' 700/P-700.
- Cyclic ETS OR PS-I is activated by wavelength of light greater than 680 nm.
- It occurs at grana thylakoids and stroma thalakoids.
- During Cyclic ETS the electron ejected from reaction centre of PS-I, returns back to its reaction cetnre.
- In cyclic ETS, **no oxygen evolution** occurs, because photolysis of water is absent.
- Phosphoryltion takes place at two places, thus **two ATP** generate in each cyclic ETS.
- $NADPH_2$ (reducing power) is not formed in cyclic process.
- Plastocynanin (PC) is **Cu-containing** blue protein in cyclic ETS.
- According to modern researches, first e^- acceptor is FRS (Feredoxin Reducing Substance), which is a Fe-S containing Protein. Earlier fd (Ferredoxin) was considered as first e^- acceptor.



CYCLIC PHOTOPHOSPHORYLATION

(III) Z-Scheme/Non-cyclic ETS and Photophosphorylation

- Both PS-I and PS-II involved in n on cyclic ETS.
- PS-II(P-680) consists of Chl-a-660, Chl-a-673, Chla-a680, Chl-a-690, Chl-b or Chl-c or Chl-d, carotenoids & phycobilins. Phycobilins present only in PS II

- It occurs at grana thylakoids only.
- The e^- ejected from PS-II **never bak** to **chl-a-680** (Reaction centre) & finally gained by NADP. Thus gap of e^- in PS-II is filled by photolysis of water as a result, **oxygen evolution occurs in Z-scheme.**

- Each turn of non cyclic ETS produces **1 ATP** and **2NADPH$_2$** (4 mol. of water is photolysed and 1 O_2 released)

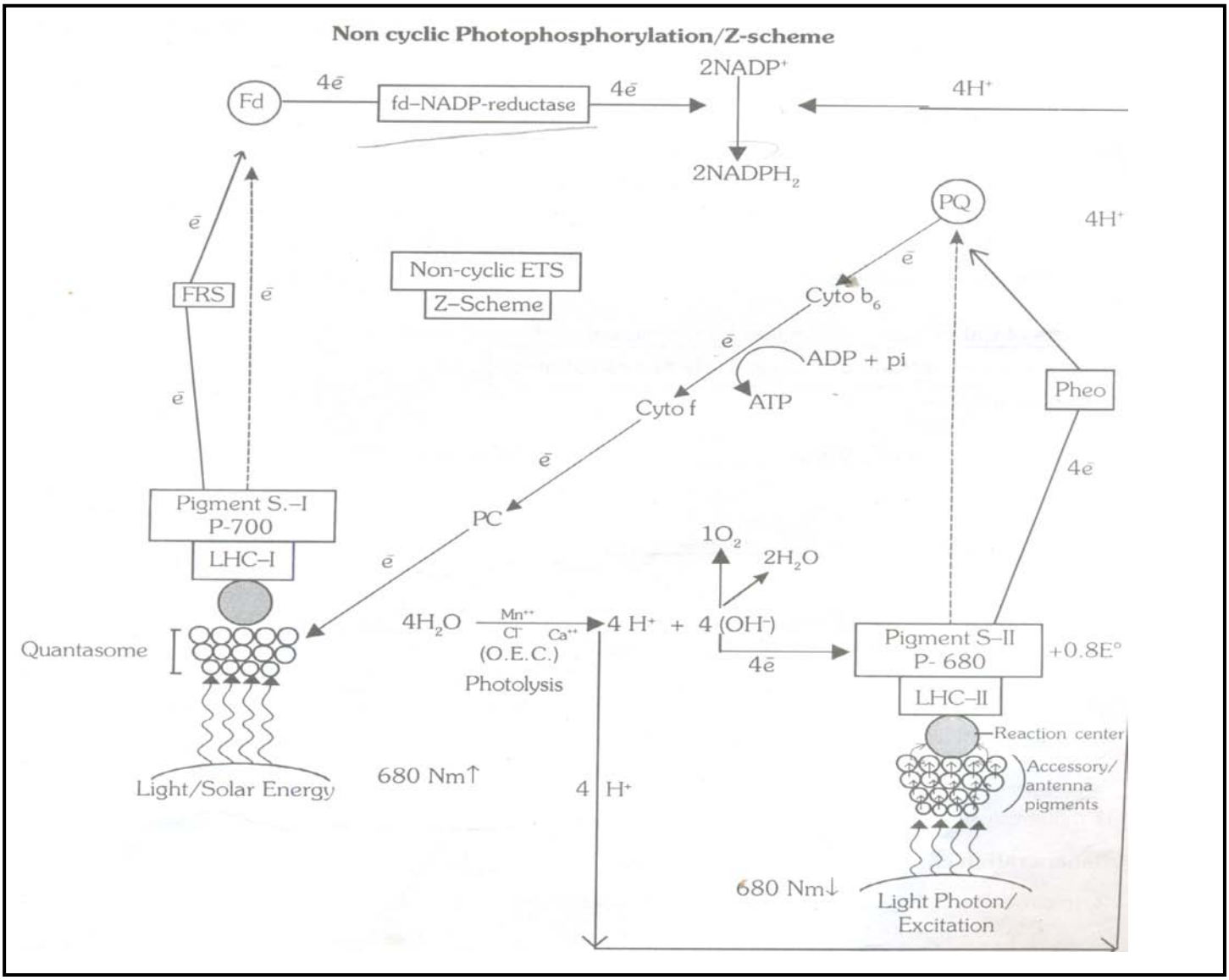
6 times **Z - Scheme** → 12 $NADPH_2$, 6 ATP

6 times **Cvclic ETS** → 12 ATP

→ 12 $NADP_2$ + 18 ATP

Total : 54 ATP equivalent

(:1 NADPH2 = 3 ATP)



- **12 $NADPH_2$ + 18 ATP** are required **as assimilatory power** to produce one molecule of Glucose in **dark reaction,** thus **6 turns of Z-scheme** are necessary for the production of one glucose molecule by calvin cyclie.
- Additional 12 ATP come from **6 turn of cyclic ETS.** (over all 54 ATP equivalents)
- primary e^- acceptor in non-cyclic reaction is PQ or plastoquinone. Recently **pheophytin** (structure like chl. a without Mg) is considered as **Is e^- acceptor** in Z-scheme.
- **Plastocynanin** (PC) in link between PS-I and PS-II in non cyclic ETS. (Some scientists-cyto-f)
- Final e^- acceptor in Z-scheme in **$NADP^+$** (Hill regent)
- During Non-Cyclic ETS energy flow takes place from PS II to PS I.

[B] Dark Reaction/Black man Reaction/Calving Cycle/C_3-Cycle/Biochemical phase/ Carbon assimilation/photosynthetic carbon reduction cycle (PCR- Cycle)/Reductive pentose phosphates pathway-

- Blackman reaction is called as **dark reaction,** because no direct light is required for this. Calvin presented these reactions in cyclic manner & thus called as **Calving cycle.**
- I^{st} stable compound of Calving cycle is **3C-PGA** (Phosphoglceric acid) thus Calvin cycle is called as **C_3 - cycle.** (First compound is unstable, 6C keto acid)
- Study by Calvin was on **Chlorella** & **Scenedesmus.** During his experiment he used **chromatography** & **radioisotopy (C^{14})** techniques for detecting reactions of C_3 - cycle.
- **Rubbisco** (Ribulose bis-phosphate carboxylase-oxygenase) is main enzyme in C_3 - cycle, which is present in stroma & it makes 16% protein of chloroplast. Rubisco is most abudant enxyme.
- CO_2 - acceptor in Calvin cycle is **RuBp.** This carboylation reaction is catalysed by Rubisco.
- C_3, C_4, C_5, C_6 and C_7 monosaccharides are intermediates of calving Cycle.
- C_3 = Phosphoglyceraldehyde and DHAP, C_4 = Erythorese, C_5 = Xylulose, Ribose, C_7 = Sedoheptulose.
- The largest monosaccharide in living are 7C-**Sedoheptulose-P (Ketose)**
- **Warburg effect -** Inhibitory effect of high conc. of O_2 on photosynthesis is called as Warburg effect (It is due to Phtorespiration).
- **6 turns** of Calvin cycle are required for the formation of one glucose.

Biochemical reaction of Calvin cycle are as follows -

- **Carboxylation**

(1) 6, RuBp (RuDp) + 6, CO_2 (HCO_3^-) $\xrightarrow[\text{(Carboxy dim utase)}]{\text{Rubisco}}$ 6C unstable comp. $\longrightarrow$ 12, 3, -PGA (3C)

- **Glycolytic reversal** $\rightarrow$

(2) 12 Mol $\underset{(3C)}{3-PGA}$ + 12 ATP $\xrightarrow{\text{Triokinase}}$ 12, 1,3-BiPGA

(3) 12, 1,3-BiPGA $\xrightarrow[12NADPH_2 \quad 12NADP^+]{\text{Dehydrogenase}}$ 12, 3-PGAL (Triose phosphate) + $12H_3PO_4$

(4) 5 Molecules of PGAL isomerise in to DHAP (Dihydroxy acetone phosphate).

3, PGAL + 3 mol. DHAP $\xrightarrow{\text{Aldolase}}$ 3, Gructose - 1, 6 Biphophate
9C(3C × 3) (9C) (3C × 3) (18C) (6C × 3)

[1 mol. fructose $\xrightarrow{\text{Isomerase}}$ $C_6H_{12}O_6$ Glucose $\longrightarrow$ Sucrose/Starch]

- **Regeneration of ribulose 1,5 biphosphate** $\rightarrow$

(5) 2, frusctose - P + 2, PGAL $\xrightarrow{\text{Transketolase}}$ 2 Mol, Erythorose -P + 2 Mol. Xylulose-P
(12C) (6C) (8C) (10C)

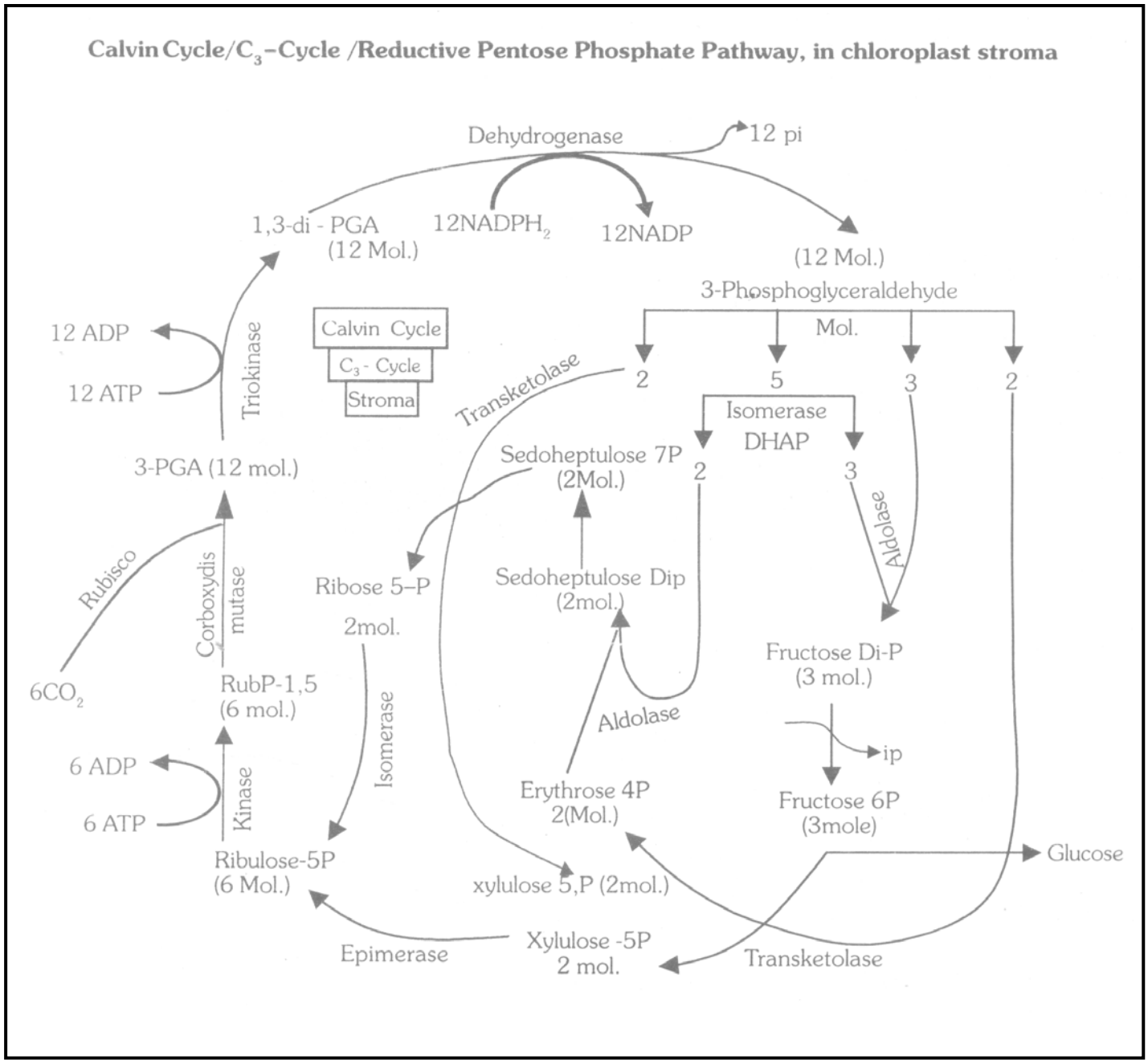
(6) 2, Erythrose -P + 2, DHAP $\xrightarrow{\text{Aldolase}}$ 2, Sedoheptulose-1, 7-BiP
(8C) (6C) (14C)

(7) 2, Sedoheptulose-P + 2 PGAL $\xrightarrow{\text{Transketolase}}$ 2, Xylulose-P + 2, Ribose-P
(14C) (6C) (10C) (10C)

(8) 2 + 2, Xyluose-P $\xrightarrow{\text{Epimerase}}$ 4, Ribulose-5 P
(20C)

(9) 2, Ribose - 5P $\xrightarrow{\text{Isomerase}}$ 2 Ribulose - 5P
(10C)

(10) 6, Ribulose - 5P+ 6ATP $\xrightarrow{\text{Kinase}}$ 6, Ribulose-1, 5 -BiP (CO_2 acceptor) + 6 ADP



DIVERSITY IN DARK REACTIONS

CO_2 concentrating mechanism/Co-operative photosynthesis/Dicarboxylic acid cycle (DCA cycle/C_4 cycle/Hatch & Clack Pathway

- **Kortschak and Hartt** first observed that 4C, OAA (Oxaloacetic Acid) is formed during dark reaction in sugarcane leaves.
- **Hatch** & **Slack** (1967). Studies in detail and proposed pathway for dark reactions in **sugarcane** & **mize leaves.**
- First stable product of this reaction is OAA. Which is 4C, DCA (Dicarboxylic Acid), thus Hatch & Slack pathway is called as **C_4 cycle** or **DCA cycle.**

- C_4-cycle occurs in 1500 sps. of 19 families of angiosperm, but most of the plants are monocots, which belong to **Graminae** & **Cyperaceae (ugarcane, Maize, Sorphum, Oat, Chloris, Sedges, Bajra, Panicum, Alloteropsis etc.)**

- **Atriplex hastata & A. Patula** are temperatere sps., which are C_3 - plants.

- Dicots with C_4 cycle are **Euphorbia sps., Amaranthus, Chenopodium, Beorhavia, Atriplex rosea, Portulaca, Tribulus.**
- Wheat and barley (monocot) are C_3 species. rice up. develops as C_4 plants by plant breeding scientists
- **Kranz(Wreadth) anatomy** - Present in leaves of C_4 plants.

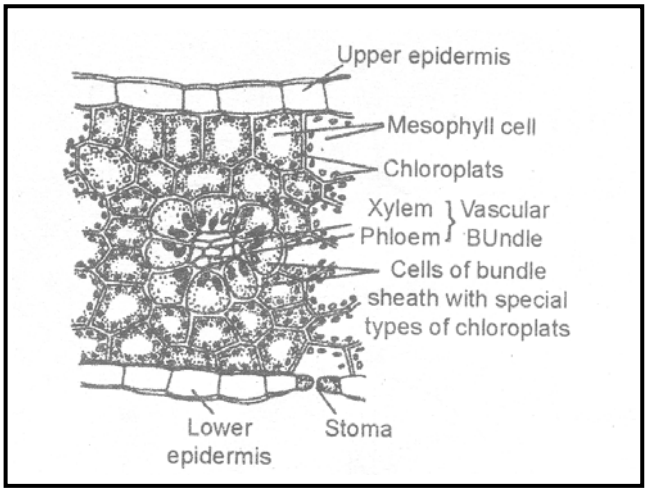
(i) Green bundle sheath cells (CS cells) present around the vascular bundles.

(ii) Dimorphic choroplants present in leaf cells. Chloroplast of B.S. cells or **Kranz cells** are larger and without grana.
Mesophyll chloroplast are small and with grana.

- Rubisco present in BC cells, while PEPC are in mesophyll cells.

- In the C_4-Plant, C_3-cycle occurs in bundle sheath cells, while c_4-cycle occurs in mesophylls.

- Thus operation of **Hatch and Slack pathway** require cooperation of both Photosynthetic cell i.e. mesophyll cells and BC cells.



- Photosynthetically C_4 plants are more efficient as there is no Warburg effect or photorespiration in C_4 plants, Because at the site of Bu bisco (BS cells) less O_2 is present (mesophyll cells pumps more CO_2 for C_3 cycle).

- C_4- plants found in tropical habitats and adapted themselves, with high temerature, low ater availabiilty and intense light.

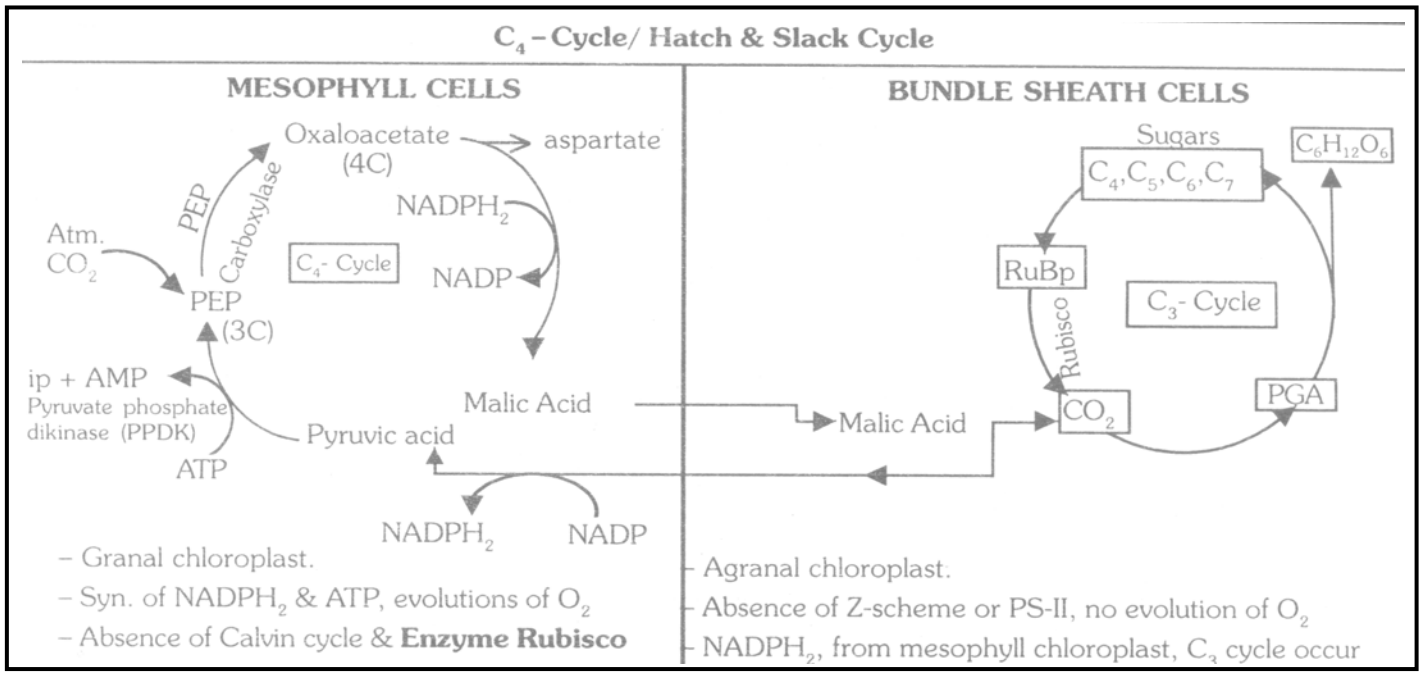
- If concentration of O_2 increases artificially, then photorespiration may be started in C_4 plants.

- Ist carboxylation in C_4-cycle occurs by **PRPCase** in mesophyll cytoplasm, while second carboxylation or final CO_2 fixation by C_3 cycle occurs in bundle sheath cells.

- CO_2 acceptor in C_4 mesophyll in **PEP (Phosphoenol Pyruvate).** (3C-compuond), while RuBp is bundle sheath cells.

- 12 $NADPH_2$ & 30 ATP needed for production of 1 Hexose (Glucose) in C_4 - plants.

- **Pyruvate phosphate dikinase (PPDK)** ($ATP \rightarrow AMP$) is a low temperature sensitive enzyme of C_4 and CAM plants due to this C_4 plants better phtosynthesizes at high temperature.



Special features of C_4 plants :

(1) C_4 plants are more efficient plants at present CO_2 concentration

(2) Present level of atomospheric CO_2 is generally not limiting factor for C_4 plants.

(3) C_4 plants posses low CO_2 compensation points (8-10ppm)

(4) The productivity (fertility) does not increase in C_4 plants, when CO_2 concentration is increases because :

(a) Mesophyll cells provide more CO_2 for Calvin cycle.

(b) The concentration of CO_2 around the **site of Rubisco** is higher in C_4 plants, thus little or no chance of photorespiration.

CAM-Plants/Crasulacean acid metabolism / Dark CO_2 fixation / Dark Acidification

- **Oleary** and **Rouhani** discovered CAM-process in members of **Crassulaceae** family. Succulent xerophytie plans. Eg. are - **Kalanchoe, Bryophyllum, Sedum, Kleinia, Opunitia, Crassula, Agave, Aloe, Euphorbiasps, Pineapple, Welwistschia** (Gymnosperm) etc.

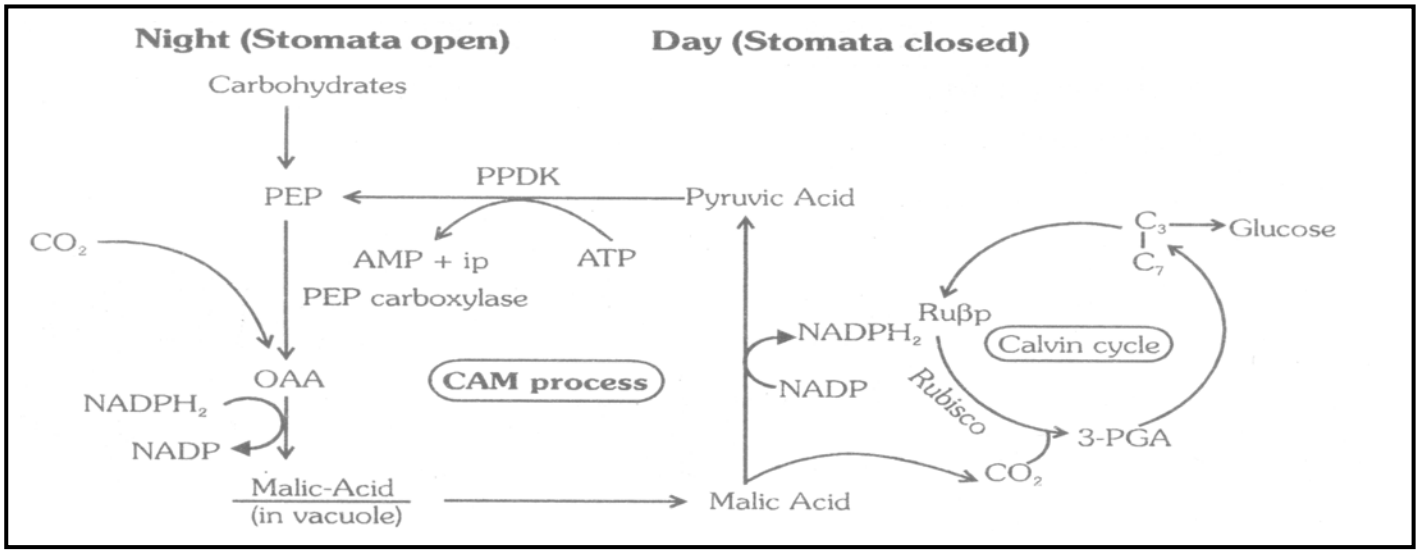
- Primary acceptor of CO_2 is **PEP** (Phosphoenol pyruvate) and oxaloacetic acid is the first product of carboxylation reaction.

- In CAM plants stomata are of **scotoactive type,** s initial CO_2 fixation is found in night but light reactions operates at day time. Final CO_2 fixation (C_3 cycle) occurs in day time. EPEPcase induces carboxylation reaction in night

- **PEP caboxylase** & **Rubisco** present in mesophyll cells.(**No Kranz- anatomy)**

- In CAM plants 30 ATP and 12 $NADPH_2$ are required as assimilatory power for 1 glucose synthesis.

- CAM plants exhibits ecophysiological adaptation with xeric habits.



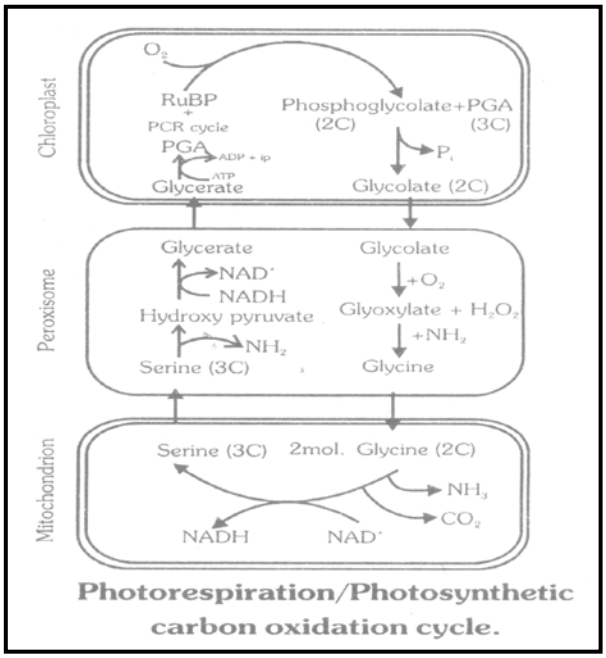
Photosynthetic carbon oxidation cycle /C_2 cycle/Photorespiration/Glycolate - Metabolism

- Term was given by **'Krotkov'**
- First of all **Krotkow** et. all indicated that more CO_2 evolves during day time in C_3 plants.
- **Decker** & **Tio** discovered photorespiration and clarified that **C_2-cycle** or **glycolate pathway** operates during day time in C_3-plants & **Rubisco acts as oxygenase** at **higher concenration of O_2** and **low CO_2 concentration** in the C_3 - green cells.
- The light dependent uptake of O_2 & release of CO_2 in C_3 Photosynthetic cell is called **photo respiration.**
- Photorespiration is not linked with ATP generation (in place ATP are consumed) as ordinary **dark respiration,** thus it is harmful or wasteful process linked with C_3 cycle.
- It occurs in **chloroplst, peroxisome & mitochondria (three cell organalle reaction).**

$$RuBP + CO_2 \xrightarrow{\text{Rubisco}} 2PGA$$

$$RuBP + O_2 \xrightarrow[\text{Low } CO_2,\ \text{High } O_2 \text{ con}^n,\ \text{High temp.}]{\text{RuBP}-\text{Oxygenase}} 1\text{ PGA} + 1\text{ Phosphoglycolate.}$$

- During photorespiration, 75 percent of the carbon lost by the oxygenation of RUBP is recovered. Because two molecules of glycine (2C + 2C = 4C) form one molecule of serine (3C). During this one carbon releases in form of CO_2 in mitochondria thus 25 percent carbon is lost.
- This serine molecule changes into PGA via different reactions of C_2 cycle.
- H_2O_2 (Peroxisome) and NH_3 (Mitochondria) produces in photorespiration.
- Glycine (Peroxisome) and serine (mitochondria) are also formed in photorespiration.
- Scientists are trying to change C_3 spe. into C_4 sps.
- It is assumed that in C_3 plans, if photorespiration does not occur, then increases O_2 conc. which oxidise (Photoxidation or Solarization) the different protoplasmic parts of photosynthetic cell as high light intensity.



Photorespiration/Photosynthetic carbon oxidation cycle.

FACTORS AFFECTING PHOTOSYNTHESIS

(1) Light

(a) Light Quality or wavelength $\longrightarrow$ Max^{m} Photosynthesis takes place n **red light** than in Blue light. But rate of Photosynthesis is highest in white light. Minimum in green light.

(b) Light Intensity - Rate of Photosynthesis is greater in intense light than diffused light. But at higher light intensity photooxidation (solariztion) occurs and photosynthetic apparatus my get destroyed.

- **P/R** (Photosynthesis : Respiration) Ratio at mid day o\is 1 : 1; but can reach upto 20 : 1 ratio. At the time of evening & morning rat eof Photosynthesis equal to respiration, this situation called as **light compensation point.**
- Intensity of light, at which rate of Photosynthesis, becomes equal (or compensatie) to the rate of respiration in plant (Dark respiration + photorespiration) is known as **light compensation point**. (Net Photosynthesis or net primary productivity at this point is zero,)
- Plants which are adapted to grow in high intensity of light is called **heliophytes** & plants which are adapted to grow in shade is **sciophytes.**

(c) Duration of Light -On the basis of effect of light on plants may be LDP & SDP.

- Rate of Photosynthesis is relater in intermittent light than continuous light - **Warburg.**

(2) Temperature -

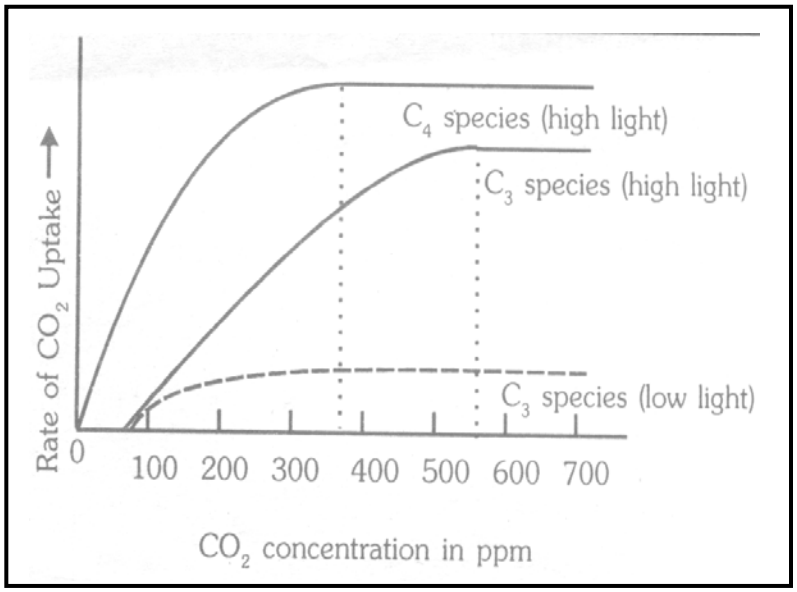
- Optimum temp. for Photosynthesis is **20-35^{0}C**
- At high temp. rate of Photosynthesis decreases due to denaturation of enzymes.
- Conifers & lichen can perform Photosynthesis at -35^{0}C, while thermal algae **Oscillatoria** at 70-80^{0}C.
- Generally different habitat plans show, different response to Photosynthesis on a given temperature.

(3) CO_2 (0.03%/314 ppm)

- An increase in CO_2 Conc^{n}. unto 1% rate of Photosynthesis is increased. Hihger CO_2 concentration. is toxic to plant & also closes stomata.

- C_4-Plants can Photosynthesize at low CO_2 conc^{n} (upto 10 ppm). "CO_2 conc^{n} at which CO_2 fixation in Photosynthesis is equal to colume of CO_2 released in respiration is **"CO_2 compensation point"** when plant saturated with full light.

- CO_2 compensation point for C_4 plants is 8-10 ppm, while for C_3 plants it is 40-100 ppm.



(4) O_2-

High O_2 conc^{n} reduces Photosynthesis due to photorespiration.

(5) Water -

Less availability of water reduces the rate of Photosynthesis (Stomata get closed)

(6) Chlorophyll -

The amount of CO_2 in grams absorbed by 1 gm. of chlorophyll in 1 hours is called as **photosynthetic number** or **assimilatory number (Wills attar & Stool).**

(7) Product -

Rate of Photosynthesis decreases, when sugar accumulates in mesophyll cells.

(8) Leaf :

Various leaf factors like **leaf age** and **leaf orientation** effect the rate of Photosynthesis.

- In young & mature leaves Photosynthesis is more than old (senescent) leaves.

(9) Inhibitors -

DCMU (Diuron/Dichloropheyl Dimenthyl Urea) **CNU (Monuron), PAN, Atrazine, Simazine, Bromocil, Isocil-** inhibit the Photosynthesis by blocking PS-II. They stop e^- flow between P-680 & PQ

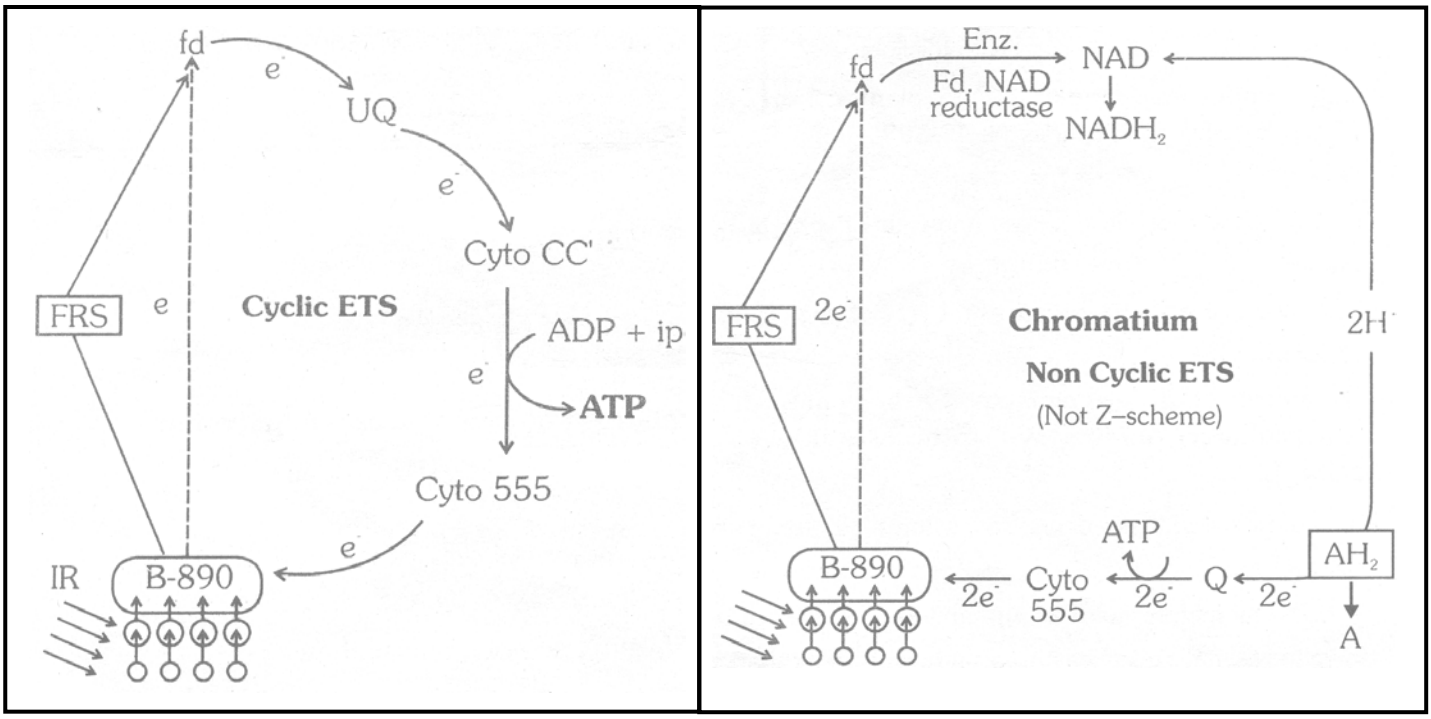
- In cyclic ETS diquat, praquat (Viologen dyes) inhibit e^- flow between P-700 & Fd.
- All these chemical are used as herbicides, which mostly block ET.

(10) Minerals : Mg and Nitrogen are essential for structure of chlorophyll and enzymes. Thus reduction in N_2 and Mg supply to plants effects adversely the rate of Photosynthesis.

- Rubisco alone accounts for more than half of total leaf nitrogen.
  Generally ald essential element affect the rate of Photosynthesis.
- **Concept of three cardinal points (Von Scach) :** The effect of the various external factors on the rate of biological processes were centered around the attempts to establish **minimum optimum** and **maximum** values knows as cardinal points.
- **Law of minimum (Liebig) -** According to it, when process if governed by a number of separate factors, then the rate of process is controlled by that factor present in minimum amount.
- **Low of limiting factors – (Blackman) :** It is the modification of Law of minimum by **Liebig.** "When a process is conditioned to its rapidity by a number of factors, then rate of process is limited by the pace of the slowest factor" (CO_2 light, chlorophyll, water, temp.)
- CO_2 becoming limiting in clear sky, but light limiting in cloudy days
- Atmospheric CO_2 is not limiting factor for C_4 plants & submerbed hydrophytes.

BACTERIAL PHOTOSYNTHESIS

- Certain bacteria are capable for Photosynthesis Eg. : **Chlorobium** (Green Sulphur), **Chromatium** (Purple Sulphur), **Rhodospiriluum, Rhdopseudomonas** (Purple non sulphur).
- Cyclic photophosphorylation is an important method in bacterial Photosynthesis.
- Absorption of Infra red spectrum takes place during bacterial Photosynthesis thus **no red drop.**
- Pigment system of bacteria denoted by -B-890 or 870
- Evolution of **O_2 is not related to** bacterial Photosynthesis, because water is not e^- donor (H_2S)
- Only one ATP is produced in each turn of cyclic Photophosphorylation, in bacteria.
- **Olson** 1970 gave a non cyclic scheme in bacterial Photosynthesis.
- $6CO_2 + 12\ H_2S \xrightarrow[\text{Pigments in chromotophores}]{\text{IRlight}} C_6H_{12}O_6 + 6H_2O + 12S.$
- Bacteria has only one pigment system, PS I(PS II is absent)



HETEROTROPHIC PLANS NUTRITION

☛ **Heterotrophs -** Heterotrophic plants are of following types -

[A] Parasites -

(1) Total stem parasites	**-**	Cuscuta or dodar (totally depend)
(2) Partial stem parasites	**-**	Loranthus, Viscum (depend on host for H_2O & minerals)
(3) total root parasites	**-**	Members of Refflesiaceae, Balanophoraceae & Orobanchaceae (totally depends on host)
(4) Partial root parasites	**-**	**Santalum album & Striga.**

[B] Insectivorous plants -

These are green plants but of insectivours habits which develop, due to deficiency of nitrogen, because they grow on N_2-deficient places (Swampy places).

(1) Nepenthes or pitcher plant -Found in north eastern parts of India (Endangerd)

(2) Utricularia or bladderwort - hydrophyte and pollution Indicator.

(3) Drosera or Sundew

(4) Pinguicula or butterwort

(5) Dionaea or venus fly trap.

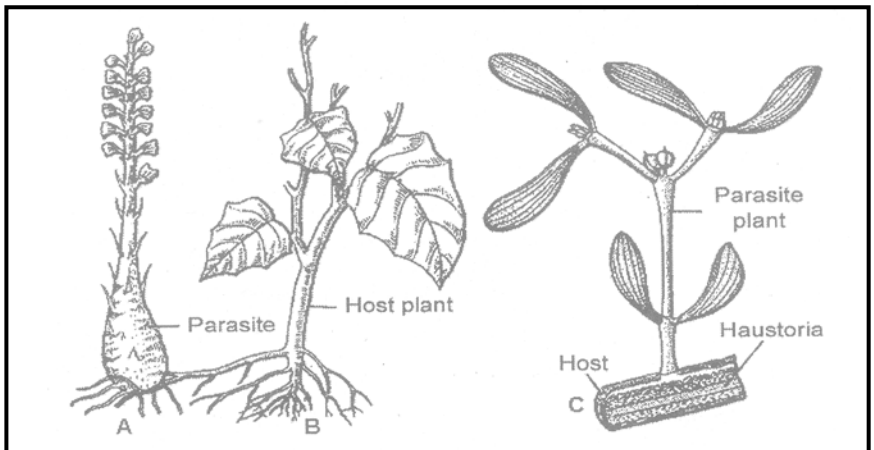
(6) Saracenia or pitcher plant with symbiotic bacteria.

(7) Aldrocanva (Water flea trap)

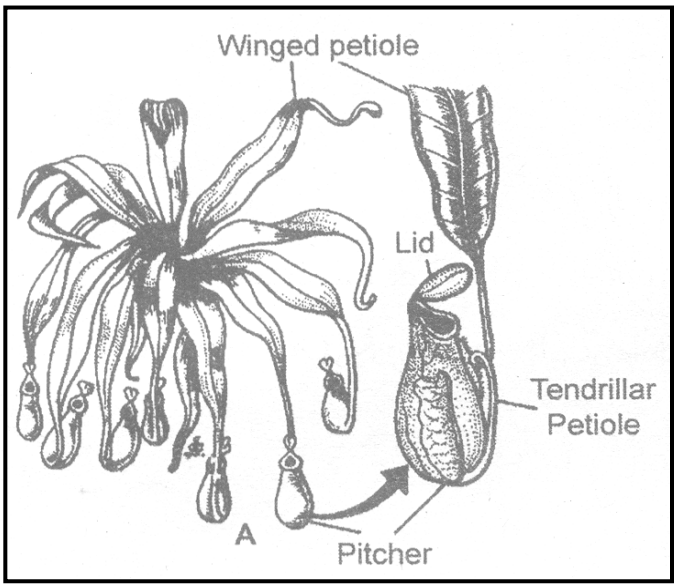
(8) Genlisea (Lobster pot trap

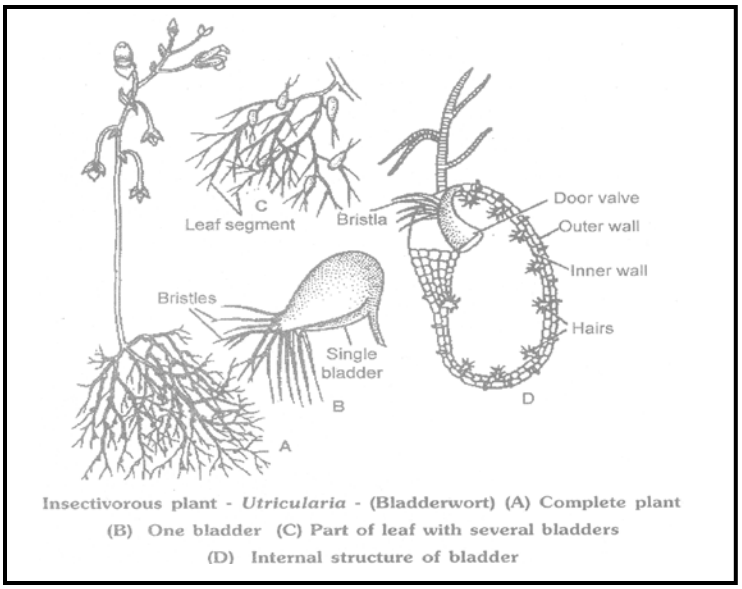
[C] Saprophytes -

No gree plants, which depend on deed organic matter - **Monotrapa** (India Pipe) **Neottia** (Birds eye nest) (**Dischidia** is a pitcher plant but not insectivorous.)

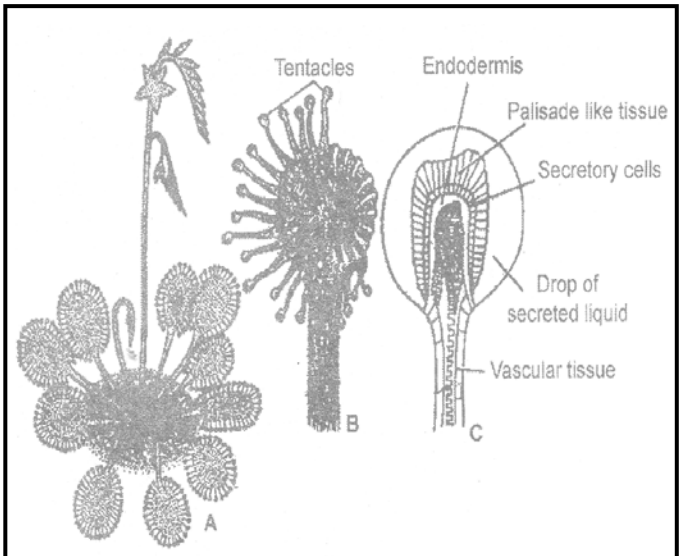


Parasitic plants-*Orobanche*
(A) A flowering plant growing on the root of *bringal*
(B) *Viscum*-Plant attached to the host stem
(C) Part of host stem is cut open to show the haustorium

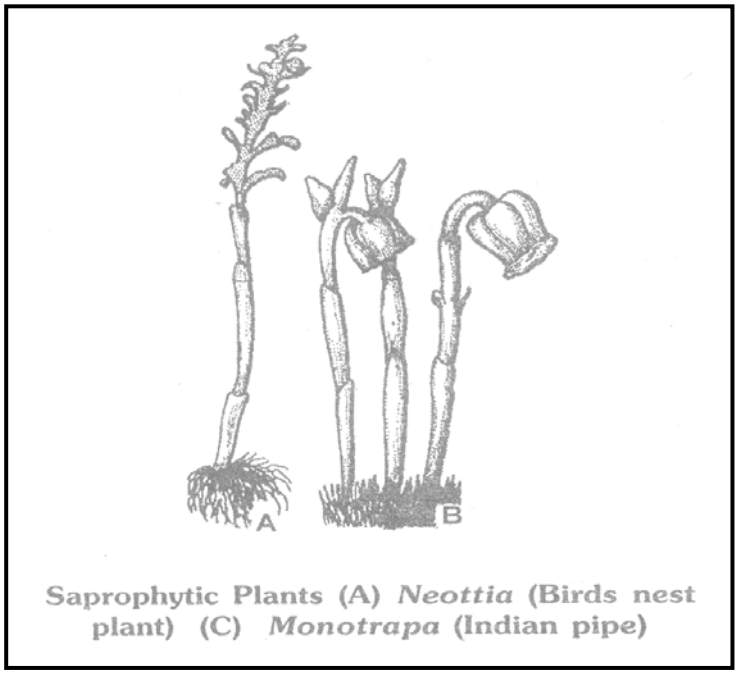




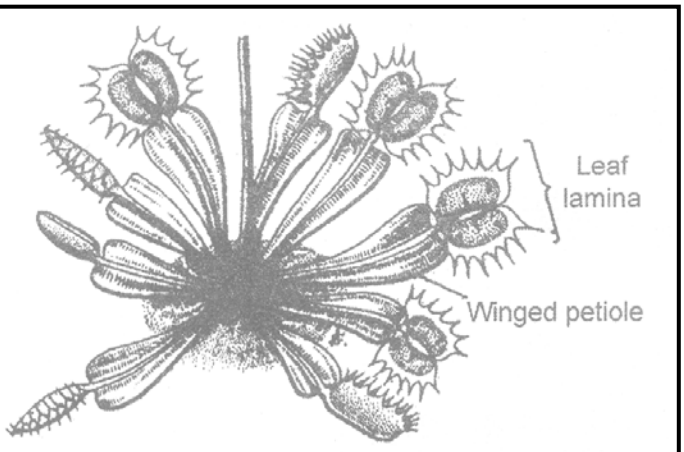
Insectivorous plant - *Utricularia* - (Bladderwort) (A) Complete plant (B) One bladder (C) Part of leaf with several bladders (D) Internal structure of bladder



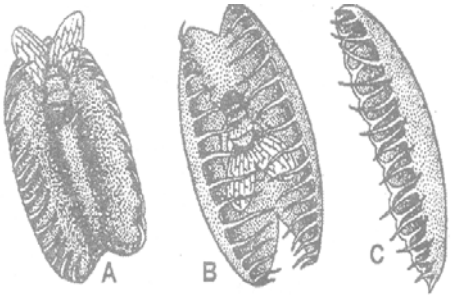
Insectivorous plant - *Drosera* (A) Complete plant (b) One leaf (C) One glandular tentacle



Saprophytic Plants (A) *Neottia* (Birds nest plant) (C) *Monotrapa* (Indian pipe)



Insectivorous plant - *Dionaea* (Venus fly trap)



Insectivorous plant *Dionaea* : Different stages in the capture of the insect

SPECIAL POINTS

- "Photosynthesis is photo-biochemical process, in which organic compound are synthesized from the inorganic raw materials (H_2O & CO_2) in presence of light energy and pigments (chl.) gas-oxygen evolved as byproduct.
- First true & oxygenic Photosynthesis started in **Cyanobacteria (BGA)**
- Roots of **Tinospora** and **Trapa** are Photosynthetic
- Modern view about Photosynthesis is conversion of **light/radiant energy into biochemical or potential energy.**
- **Absorpiton sperctrum** for Photosynthesis in visible light is **blue** & **red** wavelength.
- **ACtion spectrum** irs **red** & **blue** light in which rate of Photosynthesis is higher.
  (But rate of Photosynthesis is highest is white light than monochromatic light).
- **Function of accessory pigment carotene is -**

  Converts elementary or nasent oxygen to molecular/gaseous O_2

  O + O (elementary oxygen) + Carotene $\rightarrow$ Epoxide complex $\xrightarrow{\text{Deepoxidase}}$ O_2 + Carotene.

  Protects photoxidation (phtodamaging) of pigment system.

  Precursor of vit - A.

  Oxidation to form ABA hormone in guard cells.

- Chlorophyll pigment soluble in organic solvents like acetone, ether etc. (anthocyanin is non Photosynthetic wter soluble pigment, which present in vacuole.)
- Chlorophyll in bundle sheath of **Bermuda** grass is laos granal type.
- Photolysis of water occurs at + 0.8 E^0
- In cyanobacteria (BGA), Photosynthesis occurs on **chlorosomes** or **lamellisome** or **carboxysome.**
- PS-I is strong reductant as PS-I has good ability to reduce $NADP^+$, while PS-Ii is a strong oxidant, because it has extreme power of oxidation & photolysis of water molecule.
- 264 gm. CO_2 and 216 gm. water produced 108 gm, water 192 gm, O_2 and 180 gm. glucose.
- Annula production of Photosynthesis is 170 billion tones of carbohydrate.
- Wilmott's bubbler apparatus proves that oxygen is evolved during Photosynthesis.
- Cytochromes are Iron - porphyrin protein discovered by MachMunn (termed by Keilin).
- Pigments except chlorphyll, present in Quantasomes are called as **accesssoary** or **antenna pigment** of light harvesting complex (LHC).
  Electrosmotic theory - By **Spanner** and **Jones** for translocation of sugar.
  Chollet and Ogran (1975) : Recognised 3 categories of C_4 plants.
  (i) **Maize and Sugarcane type : In this category malate** t ransported to bundle sheath cells and its decarboxylation gives CO_2 for C_3 cycle.
  (ii) **Panicum and Chloris type :** In this ategory malate transported into bundle sheath cells, but this changes into **oxaloacetate,** which gives CO_2 for C_3 cycle.
  (iii) **Atriplex type :** In this category the aspartate transported into bundle sheath cells, where it changes into malate, which provides CO_2 for C_3 cycle.
- I^{st} formed unstable 6-C compound during Calving cycle is **carboxy ketoribitol hiphosphate.**
- Mg^{++} acts as cofactor of both **Rubisco** and **PEPCase.**
- **Significance of photosynthesis -**
  Photosynthesis is vital process for life on planet earth as it is the only process, that links the physical and organism.
  Presence of O_2 in the atmosphere is also an outcome of photosynthesis. This oxygen is helpful to living organisms into ways :
  1.Oxidative break down of organic food meter (respiration)
  2. Making ozone (O_3), in outer layer of atmosphere, which helps in stopping the highly destructive U. V. rays.

☛ **Efficienty of photosynthesis -**

One quantum of red light = 47.6 Kcal (One red photon or quantum = 47.6 Kcal)
One glucose = 686 Kcal. (1 CH_2O = 114.3 Kcal)
8 Quantum × 47.6 Kcal = 381 energy require for fixation of one CO_2

Thus $\frac{114.3}{381} \times 100 = 30\%$

DIFFERENCES

Photorespiration	Dark Respiration
(i) Occurs in **chloroplast, peroxisome** and **mitochondria.**	(i) Occurs in **cytoplasm mitochondria.**
(ii) Wasteful process.	(ii) Useful process.
(iii) NH_3 & CO_2, H_2O_2 are produced	(iii) CO_2, H_2 O & ATP generated.
(iv) In green cells of C_3 - plants.	(iv) In all living cells.
(v) Occurs during day time only	(v) All time

Cyclic phtophosphorylation	Non-cyclic photophosphorylation
(1) Only PS-I involved in cyclic process.	(1) Both Ps-II & PS-I works in non-cyclic process.
(2) The e^- expelled from chl-700 is cycled back.	(2) The e^- expelled from reaction center is not cycled back. Its loss is compensated by e^- from H32 O.
(3) Photolysis of water and evolution of O_2 does not take place.	(3) Photolysis of water and evolution of O_2 takes place.
(4) Phosphorylation at two places.	(4) Phosphorylation at one site.
(5) $NDAP^+$ is not reduced.	(5) $NADP^+$ is reduced to NADPH.
(6) Activated by 680 NM ↑ light.	(6) Activated by 680 NM ↓

C_3 - pathway	C_4 - pathway	CAM-pathway
(1) Ist stable compound is 3-C PGA	(1) Ist stable compound is 4C O.A.A.	(1) First formed compound is O.A.A.
(2) 18 ATP & 12 $NADPH_2$ used for 1 glucose formation	(2) 30 ATP & 12 $NADPH_3$ used for 1 glucose formation	(2) 30 ATP and 12 $NADPH_2$ used for Production of 1 glucose
(3) Kranz anatomy absent	(3) Kranz anatomy present	(3) Kranz anato my absent
(4) Presence of photorespiration	(4) Absence of phtorespiration	(4) photorespiration may present
(5) One type of carboxylase enzyme, **Rubisco** only	(5) Two type of carboxylase enzyme **Rubisco** & **PEPcase**	(5) Two type of carboxylase enzyme **Rubisco** & **PEPCase**
(6) CO_2 acceptor - RUBP	(6) Priamry CO_2 acceptor - PEP & RUBP is secondary acceptor	(6) Primary CO_2 acceptor is PEP & RUBP is secondary acceptor
(7) Exhibits high CO_2 (7) compensation point (40-100 PPM)	Low CO_2 compensation point (8-10 PPM)	(7) High CO_2 compensation point (40-100 PPM)
(8) Transpiration ratio (TR) 500-1000	(8) TR - 200-300	(8) TR - 50-100