PHOTOSYNTHESIS

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Photosynthesis

- **Photosynthesis is the formation of carbohydrates from CO2 and H2O with the help of sun light in the green parts of plants (i.e., chlorophyll). It is an anabolic process.**

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

- **Ruben and Kamen (1941) proved that the source of liberated oxygen (O_2) in photosynthesis is water (H_2O) and not the CO_2.**
- **The source of oxygen in carbohydrate produced through photosynthesis is carbon dioxide (CO_2).**

- **In green plants, water (H_2O) is the hydrogen donor and is oxidised to oxygen (O_2), whereas in purple and green sulphure bacteria, H_2S is the hydrogen donor and sulphur or sulphate is the oxidation product.**
- **Photosynthesis was first appeared in cyanobacteria.**
- **Bacterial photosynthesis occurs without evolution of oxygen hence, is anoxygenic. In bacterial photosynthesis instead of water, H_2, H_2S and other compounds are employed as hydrogen donor.**
- **Bacteria have only one pigment system, which is similar to Photosystem-I (PS-I).**
- **In bacteria, trap centre is usually P8900 for bacteriochlorophyll-a. It absorbs radiations between 870-890 nm of infra red light range.**

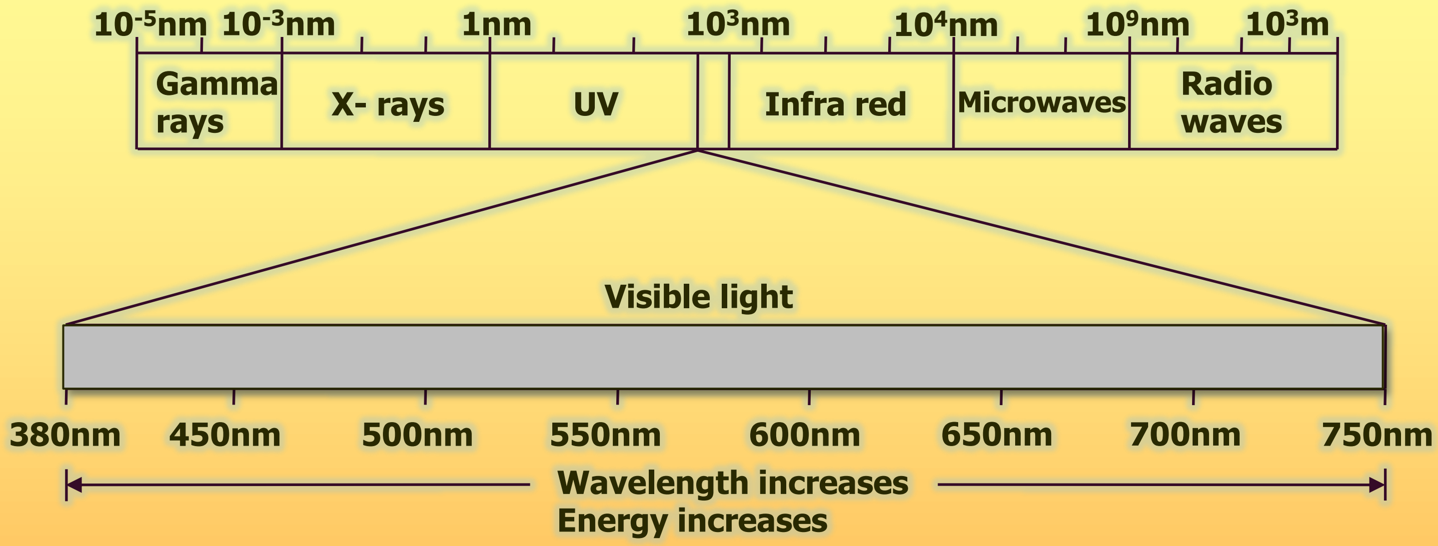
- **Both cycle and non-cyclic photophosphorylation occur but cyclic photophosphorylation is dominant. Assimilatory power consists of ATP and $NADH_2$.**
- **Thylakoids are not organised into grana in cyanobacteria (blue-green algae) and photosynthetic bacteria (prokaryotes) and are present in scattered state in cytoplasm. In these, photosynthetic pigments are distributed uniformly on or in the lamella (unilamellar thylakoids).**
- **About 90% of total photosynthesis is carried out by algae in oceans and in fresh water.**
- **About 0.2% of the sunlight energy falling on earth is utilized by photosynthetic organisms.**
- **In eukaryotes, photosynthesis takes place in chloroplasts present in cytoplasm in numbers varying from one example-** ***Chlorella*****) to about 100 (example- palisade mesophyll cells).**

- **Chloroplasts are visible under light microscope (3-10 μm diameter) and covered by two membranes. They contain chlorophyll and other photosynthetic pigments in thylakoid membranes. Thylakoids form granum. A number of grana suspended in the matrix called stroma. Thylakoids are the site of light reaction, whereas stroma is the site of dark reaction.**
- **The most common photosynthetic pigments in higher plants and green algae are chlorophyll-a (blue-green, $C_{55}H_2O_5N_4Mg$), chlorophyll-b (yellow green, $C_{55}H_70_6N_4Mg$) and carotenoids, i.e., orange red carotenes ($C_{40}H_{56}$) and yellow xanthophylls ($C_{40}H_{56}O_2$).**
- **The basic structure of all chlorophyll molecules is a porphyrin system, in which, four pyrrole (tetrapyrrole) rings linked together by methane groups form a ring system. Chlorophyll-a is essential pigment in photosynthesis because it can convert light energy into chemical energy (ATP.)**

Other pigments act as accessory pigments because they collect and transfer light energy to chlorophyll-a for photosynthesis. Carotenoids protect the chlorophyll from photo-oxidation, when exposed to high light intensity (shield pigments).

- **Carotenoid is a group of accessory photosynthetic pigments of yellowish to reddish colour, which have more double bonds (commonly tetraterpine). They are of two types- carotenes (example- β-carotene) and xanthophylls (lutein, zeaxanthin). Carotenoids absorb light radiations in the mid-region of light spectrum. They convert nascent oxygen to molecular oxygen and protect various chloroplast constituents from nascent oxygen.**
- **Phycobilins are water soluble, open tetrapyrrole pigments found in red algae and blue-green algae. These are of three types : phycocyanin (blue), allophycocyanin (blue) and phycoerythrin (red).**

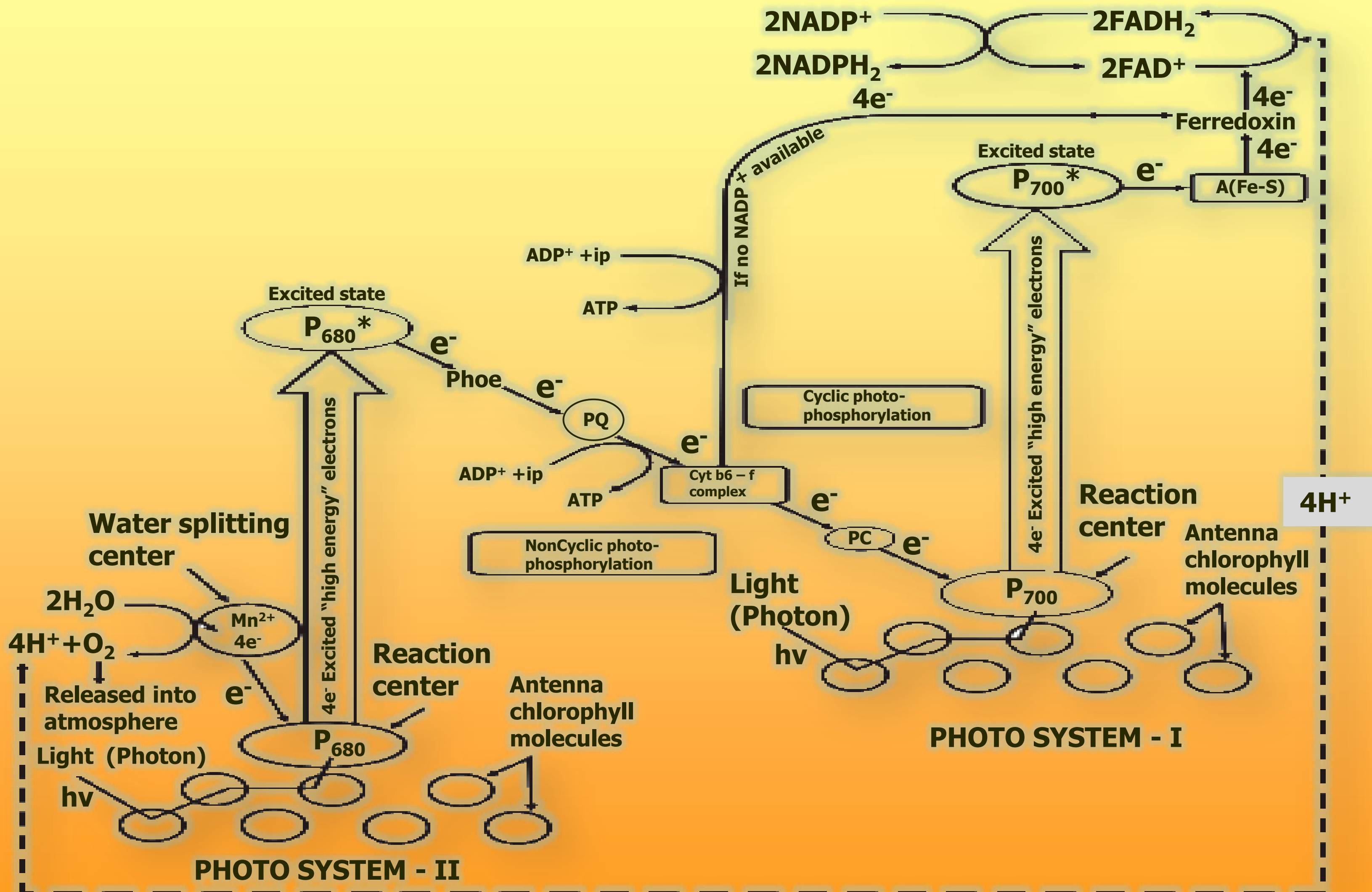
- **Light is a form of radiant energy, a narrow band of energy within the continuous electromagnetic spectrum of radiation emitted by the sun. Visible light varies from 390 nm to 760 nm.**
- **The graphic representation of curve showing the various wavelengths of light absorbed by a substance is known as absorption spectrum.**
- **Chlorophylls absorb light radiations in blue and red parts of light spectrum (430 nm and 662 nm for chlorophyll-a, 455 nm and 644 nm for chlorophyll-b).**
- **Action spectrum is a graphic representation or curve depicting the rate of photosynthesis in various wavelengths of light.**
- **Property of emission of long wave radiations by substances after attaining excited state on receipt of light energy, example- chlorophyll is known as fluorescence.**
- **Phosphorescence is the delayed emission of long wave radiation from an activated molecule.**



The electromagnetic spectrum

- **Park and Biggins (1964) coined the term quantasome for a group of pigment molecules required for carrying out a photochemical reaction. Quantasomes are present on the thylakoid membranes as a small unit. Each quantasome consists of 200-240 chlorophyll molecules, carotenoids, quinone compounds, sulpholipids, phospholipids, proteins etc.**

- **In 1950, Robert Emerson and co-workers found that if light of shorter wavelengths was provided at the same time as the longer red wavelengths, photosynthesis was even faster than the sum of two rates with either colour alone. This synergism or enhancement is known as Emerson Enhancement Effect.**
- **Robert Emerson, while determining the quantum yield of photosynthesis in Chlorella by using monochromatic light of different wavelengths noticed a sharp decrease in quantum yield at wavelengths greater than 680 mμ. Because this decrease in the quantum yield took place in red part of the spectrum. The phenomenon was called as red-drop.**
- **Quantum yield is number of oxygen molecules released per photon or quantum of light. Its value is 1/8 or 12%, i.e., evolution of one molecule of oxygen or fixation of one molecule of CO_2 requires 8 quanta.**



Z-scheme of photosynthesis

- **PAR (Photosynthetically Active Radiation) is the light of wavelengths between 400-700 nm range, that corresponds to the wave band absorbed by photosynthetic pigments.**
- **Emerson's experiments gave conclusive idea that process of photosynthesis involves two light reactions, one carried by short wavelength absorbing form of chlorophyll-a and other by pigments including a long wavelength absorbing form of chlorophyll-a. This led to the idea of two photosystems.**
- **Photosystem-II (Pigment system-II) is located in the appressed part of the grana thylakoids. The PS-II is inactive in far red light (beyond 680nm). Its reaction centre is P_{680}. It picks up electrons emitted during photolysis of water and performs non-cyclic photophosphorylation in cofuction with PS-I.**
- **PS-II is having pigments chl-b 650, chl-a 660, chl-a 670, chl-a 678, chl-a 680 and phycobilins.**

- **Photophosphorylation is the process of ATP formation from ADP with the help of energy of solar radiation. It is of two types: cyclic and non cyclic.**
- **Cyclic photophosphorylation involves only PS-I and in this, electron, expelled by excited photocentre, is returned to it after passing over a chain of electron carriers. Two molecules of ATP are synthesized in this process.**
- **Non-cyclic photophosphorylation involves light energised ATP synthesis, in which, the electron emitted by excited photocentre does not return to them. It involves both PS-I and PS-II and formation of one molecule of ATP and two molecules of $NADPH_2$ takes place in this process.**

Comparison of Non-cyclic and Cyclic Photophosphorylation

	Non-cyclic	Cyclic
Pathway of electrons	Non-cyclic	Cyclic
First electron donor (source of electrons)	Water	Photosystem-I (P_{700})
Last electron acceptor (destination of electrons)	NADP	Photosystem-I(P_{700})
Products	Useful : ATP, reduced NADP Water : O_2	Useful : ATP only
Photosystems involved	I and II	I only

- The non-cyclic electron transport is most important in photosynthesis as it supplies assimilatory power in the form of $NADPH_2$ and ATP for CO_2 assimilation and purifies the atmospheric air. It is dominating type of photophosphorylation in higher plants.

❑ Mechanism of Photosynthesis

- **Photosynthesis is anabolic redox (oxidation-reduction) process, in which, water is oxidised and CO_2 is reduced to carbohydrates. The reduction of CO_2 to carbohydrates needs assimilatory power (i.e., ATP and $NADPH_2$). The reduction of CO_2 to carbohydrate is independent of light, i.e., occurs in presence or absence o light, but production of assimilatory power (i.e., ATP and $NADPH_2$) needs light and is light depending reaction.**

Photochemical/Light Reaction/Hill's Reaction

- **It takes place only in presence of light in the grana portion of the chloroplast. The function of this phase is to produce assimilatory power consisting or reduced co-enzyme NADPH and energy rich ATP molecules. This phase involves the following reactions:**

➢ **Photolysis of water : This phenomenon is associated with pigment system-II and are catalysed by presence of Mn^{2+} and Cl^- ions. When pigment system-II is active, the water molecules split into OH^- and H^+ ions.**

The OH- ions unite to form water molecules again and release O2 and electron. It is believed that photolysis of water involves a strong oxidant, which is yet unknown and designated as Z.

$$4H_2O \rightleftharpoons H^+ + 4OH^-$$

$$4OH^- \xrightarrow[Mn^{2+}, Cl^-]{z\text{-complex}} 2H_2O + O_2\uparrow + 4e^-$$

- **Production of assimilatory power (NADPH and ATP): It has already been stated that when chlorophyll-a molecule receives a photon of light, the photocentre expels an electron with a gain of energy (23 kcal/mole). This is also known as quantum conversion because light energy converts into chemical form. The expelled electron after travelling through a series of carriers is either cycled back or is consumed in reducing NADP to NADPH + H^+. The extra energy carried by the electron is utilised in the formation of ATP molecules at certain places, during its transport. This process of formation of ATP from ADP and inorganic phosphate (iP) in photosynthesis is called photophosphorylation.**

- **The whole scheme of transfer of electrons, starting from the PS-II uphill to the acceptor, down the electron transpart chain to PS-I excitaion of electrons, transfer to another acceptor and finally down hill to $NADP^+$ causing it to be reduced to $NADPH_2$ is called the Z-scheme.**
- **In Z-scheme, the main electron acceptors are cytochromes, plastoquinones and plastocyanin.**
- **Cytochromes : Cytochromes are small proteins that contain a co-factor heme, which holds an iron atom. The iron carries electrons and cycles between the +2 and +3 oxidation states. Cytochromes are intrinsic membrane proteins; they are integral part of the chloroplast's thylakoid membranes and cannot be removed without destroying the membrance. Consequently, they carry electrons only between sites that are extremely close together within a membrane rather than diffusing throughout the stroma as NADPH does.**

- **Plastoquinones : Plastoquinones, like cytochromes, transport electrons over short distance within a membrane. After they pick up two electrons, they also bind two protons. Their long hydrocarbon tail causes them to be hydrophobic, so they dissolve easily into the lipid component of chloroplast membrane.**
- **Plastocyanin : Like cytochromes, plastocyanin is a small protein that carries electrons on a metal atom, in this case copper. When oxidized, the copper ion is in the +2 oxidation state, but as it picks up the electron, it goes to the +1 oxidation state. It is reduced one level. Plastocyanin is loosely associated with chloroplast membranes; it can move a short distance along the surface, but it does not travel far.**

Dark Reaction or Blackman's Reaction or Calvin Cycle

- **Dark reaction was discovered by F F Blackman (1905) and later on studies in detail by Calvin, Benson and J Bassham and for this work they were awarded by Nobel Prize (1961).**
- **Dark reaction is purely enzymatic reaction, which occurs in stroma of chloroplast.**
- **The techniques used for different steps of dark reaction is purely enzymatic reaction, which occurs in stroma of chloroplast.**
- **The techniques used for different steps of dark reaction were Radiactive tracer technique by using radioactive carbon C^{14}, Chromatography and Autoradiography.**
- **Chlorella and Scendesms were two algae, which were used in the study of dark reaction.**
- **The Calvin cycle is found in all photosynthetic, plants including both C_3 and C_4 plants.**

- **The path of carbon assimilation was given by Calvin, Benson and Bassham (1949). This is also known as Calvin cycle or C_3 cycle (as first) stable product is three carbon compound 3-phosphoglyceric acid). In this cycle, first CO_2 acceptor molecule is RuBP or RuDP (Ribulose 1, 5-biphosphate) and the enzyme catalyzing this reaction is RuBP carboxylase (RUBISCO).**
- **Calvin cycle involves three steps, i.e., carboxylation, reduction and regeneratin.**
- **Carboxylation- Carboxylation is the fixation of CO_2 into a stable organic intermediate. Carboxylation is the most crucial step of the Calvin cycle, where CO_2 is utilised for the carboxylation of RuBP. This reaction is catalysed by the enzyme RuBP carboxylase, which results in the formation of two molecules of 3-PGA. Since this enzyme also has an oxygenation activity it would be more correct to call it RuBP carboxylase-oxygenase or RUBSICO.**

- **Reduction – This is a series of reactions that leads to the formation of glucose. The steps involve utilisation of 2 molecules of ATP for phosphorylation and two of NADPH for reduction per CO_2 molecule fixed. The fixation of six molecules of CO_2 and 6 turns of the cycle are required for the removal of one molecule of glucose from the pathway.**
- **Regeneration – Regeneration of the CO_2 acceptor molecule RuBP is crucial if the cycle is to continue uninterrupted. The regeneration steps require one ATP for phosphorylation to form RuBP.**
- **In Calvin cycle, only one carbon (as CO_2) is taken in at a time so it takes six turns of the cycle to produce a 6-carbon hexose sugar.**
- **In Calvin cycle, 16 ATP and 12 $NADPH_2$ are required for the synthesis of one molecule of hexose sugar.**

Energy Utilization and Production During Calvin Cycle

In	Out
Six CO_2	One glucose
18 ATP	18 ADP
12 NADPH	12 NADP

Types of Carbon dioxide Processing in C_3, C_4 and CAM Plants

	C_3-Plants	C_4- Plants	CAM Plants
Ultimate carboxylase	RuBP carboxylase	RuBP carboxylase	RuBP carboxylase
Adjunct metabolism	None	CO_2 transfer	CO_2 storage
Adjunct carboxylase	None	PEP carboxylase	PEP carboxylase
Photorespiration	High	Low	Moderate
Stomata open	Day	Day	Night

Main Differences between Light Dependent and Light Independent Reactions

Character	Light Dependent Reactions	Light Independent Reactions
Location in chloroplasts	Thylakoids	Stroma
Reactions	Required light Light energy causes the flow of electros from electron 'donors', to electron 'acceptors', along a non-cyclic or a cyclic pathway. Two photosystem-I and II are involved. These contain chlorophylls, which emit electrons when they absorb light energy. Water acts as an electron donor to the non-cyclic pathway. Electron flow results in production of ATP (Photophosphorylation) and reduction NADP	Do not require light Carbon dioxide is fixed, when it is accepted by a 5C compound ribulose bisphosphate (RuBP), to form two molecules of a 3C compound glycerate phosphate (GP), the first product of photosynthesis. A series of reactions occurs called the Calvin cycle, in which, the carbon dioxide acceptor RuBP is regenerated and GP is reduced to a sugar
Overall equation	$2H_2O + 2NADP^+ \xrightarrow[\text{Chlorophyll}]{\text{Light}} O_2 + 2NADPH + 2H^+$ Also ADP + Pi $\rightarrow$ATP (variable amount)	$CO_2 + H_2O \rightarrow (CH_2O)$ 3ATP → 3ADP + 3Pi 2NADPH + 2H + → 2NADP + $2H_2O$
Result	Light energy is converted to chemical energy in ATP and reduced NADP. Water splits into hydrogen and oxygen. Hydrogen is carried to reduced NADP and oxygen is a waste product	Carbon dioxide is reduced to carbon compound such as carbohydrates, using the chemical energy in ATP and hydrogen in reduced NADP
Summary (omitting ATP and NADP)	Light energy + chlorophyll O_2 $4H^+$ $4e^-$ CO_2 + H_2O H_2O $[CH_2O] + 2H_2O$ Sugar	Sugar, containing energy from light is made from carbon dioxide and water

Factors Affecting Photosynthesis

- Law of limiting factors was proposed by F F Blackman in 1905. According to this law, by a number of separate factors, the rate of the process is limited by the pace of the slowest factor' (i.e., factor present in minimum amount).
- Usually, in the morning and evening, the rate of respiration is approximately equal to rate of photosynthesis, there shall not be any apparent gaseous exchange. The O_2 evolved during photosynthesis will be utilized in respiration and CO_2 evolved during respiration will be used in photosynthesis. This stage is theoretically called compensation point.
- Maximum photosynthesis occurs in blue and red light, while minimum photosynthesis takes place in green light. Red light is more efficient in photosynthesis as compared to blue light. However, maximum photosynthesis rate has been observed in full sunlight.

- **In shade plants like oxalis (sciophytes), compensation point is 25-100 ft candles and 100-400 ft candles in sun plants (heliophytes) like *Delbergia*. Optimum light intensity is 10% of full sunlight for shade plants and 50-70% of full sunlight for C_3 sun plants. In case of C_4- plants, saturation point is not reached even in full sunlight.**
- **Very high light intensity decreases the rate of photosynthesis and this phenomenon is called as solarisation. It may be due to photoinhibition and photoxidation.**
- **Atmospheric concentration of CO_2 is 0.03%(300 ppm). Increase in this concentration upto 0.1% increases the rate of photosynthesis in plants. Compensation point is reached at 50-100 ppm in C_3-plants and 1-10 ppm in C_4-plants.**
- **Temperature affects only enzyme controlled dark reaction. The optimum temperature is 10-35°C for C_3-plants and 30-45 °C for C_4-plants. The maximum temperature, at which photosynthesis can occur, is 55 °C in desert plants and 75 °C for some algae found in hot springs.**

- **Photosynthesis stops in many plants at 0 °C but in some conifers, it occurs even at -35 °C, when temperature is increases from minimum to optimum, the rate of photosynthesis doubles for optimum, the rate of photosynthesis doubles for every 10 °C rise in temperature. Above optimum temperature, there is initial rise followed by a fall.**
- **In C_3-plants, optimum oxygen for photosynthesis is 2.5%. Rate of photosynthesis in C_3-plants is reduced at normal atmospheric concentration of oxygen. No such effect is found in C_4-plant.**
- **Above 21%, there is reduction in photosynthesis. This effect was reported by Warburg, so it is called as Warburg effect. This is due to O_2 is a strong quencher of excited state of chlorophyll and high concentration of O_2 converts RuBP carboxylase to RuBP oxygenase.**

- **DCMU (Dichlorophenyl dimethyl urea) is a herbicide, which inhibits O_2 evolution and non-cyclic photophosphorylation. CMU (Chlorophenyl dimethyl urea) also shows similar effect.**
- **Sulphur dioxide, ozone, chlorofluoro carbon, other atmospheric pollutants and deficiency of minerals such as Mg, Fe, Cu, Zn, Mn, N decrease the rate of photosynthesis.**
- **Accumulation of food in the chloroplant reduces the rate of photosynthesis. Synthesized organic food is translocated in plants in the form of sucrose through sieve tubes or sieve cells to phloem and then phloem is responsible for translocation of organic food. This can be demonstrated by girdling experiment (removal of bark in the form of ring). Normally girdling is performed to increase fruit size since ages. This prevents downwards translocation of nutrients.**

C_3, C_4 and CAM Plants

- In C_3-plants (the most common type of plants), carbon dioxide combines with 5-carbon ribulose-diphosphate to produce two molecules of 3-carbon phosphoglyceric acid (PGA). These plants exhibit only Calvin cycle (C_3-cycle) in dark reaction.
- Almost 85% of plant species are C_3-plants, including cereals, (example- barley, rice, oat, wheat) groundnut, sugarbeet, cotton, tobacco, spinach, soybean, most trees and loan grasses.
- In C_4-plants, example- maize, sugarcane, sorghum, sun plant etc, there is a special Kranz anatomy, in which, mesophyll cells to form four carbon oxaloacetic acid and malic acid, which are then transported to the bundle sheath cells where carbon dioxide is released to go into the Calvin cycle. This pathway of carbon dioxide fixation is called Hatch and Slack's cycle.
- C_4-pathway was first reported in members of family- Poaceae or Gramineae (grasses) inhabiting in tropical areas or sub-tropical area.

Differences between Mesophyll and Bundle Sheath Chloroplasts

Mesophyll Chloroplasts	Bundle Sheath Chloroplast
Large grana	No grana (or very few and small)
Therefore, light-dependent reactions favoured, so plenty of ATP, reduced NADP and O_2 generated.	Therefore, light-dependent reactions occur a very low rate, so little reduced NADP, ATP or O_2 generated.
Virtually no RuBP carboxylase so no CO_2 fixation (CO_2 fixation occurs in cytoplasm by PEP carboxylase)	High concentration of RuBP carboxylase so CO_2 fixation occurs as in C_3 plant but more efficiently
Little starch	Abundant starch grains

Some Families, which Have C_4-plants

Family	Example
Aizoaceae	Ice plants
Amaranthaceae	Amaranthus
Asteraceae	Aster daisies
Chenopodiaceae	Pigweeds, beets
Cyperaceae	Sedges
Euphorbiaceae	Spurges
Poaceae	Grasses
Nyctanginaceae	Four O’ clock, Bougainvillea
Portulacaceae	Purslanes
Zygophyllaceae	(no familiar example)

- **All known C_4-plants are angiosperms. There is no known C_4-plant belongs to either gymnosperms, bryophytes, pteridophytes or algae.**
- **C_4-plants have a characteristic leaf anatomy called Kranz anatomy, in which, two types of chloroplasts are present.**
- **In C_4-plants, CO_2 acceptor molecule is PEP (Phosphoenol pyruvate) instead of RuBP in C_3-plants and catalyzing enzyme is PEP-carboxylase.**
- **In C_4-plants, two carboxylation reactions take place, first in mesophyll chloroplast and seconds in bundle sheath chloroplast.**
- **In C_4-plants, 30 ATP and 12 $NADPH_2$ are required for the formation of one molecule of hexose sugar (glucose).**
- **CAM (Crassulacean acid metabolism) is an alternative of C_3 and C_4-pathway of CO_2 fixation.**

- **This pathway was first of all reported in Bryophyllum, a member of family- Crassulaceae and hence, is called crassulacean acid metabolism.**
- **In CAM plants, stomata open during night and close during day time. There is no Kranz anatomy but dark acidification takes place, i.e., during night malic acid is formed. This malic acid breaks up into CO_2 and pyruvic acid in day time and CO_2 released is utilized in C_3 cycle.**

Main Differences between C_3-plants and C_4-plants

CHARACTER	C_3-PLANTS	C_4-PLANTS
Representative species	Most crop plants, example cereals, tobacco beans	Maize, sugarcane
Light intensity for maximum rate of photosynthesis	10,000-30,000 foot candles	Not saturated at 10^5 lux
Effects of temperature rise from 25°C to 35°C	No change in rate or lower rate	50% greater at 35°C
Point, at which no more CO_2 can be taken up	40-60 ppm CO_2	Around zero ppm CO_2
Water loss per gram dry mass produced	450-950	250-350

Carbon dioxide fixation	Occurs once	Occurs twice, first in mesophyll cells, then in bundle sheath cells Mesophyll cells	Bundle sheath cells RuBP
Carbon dioxide acceptor	RuBP, a 5C compound	PEP, a 3C Compound	RuBP
Carbon dioxide-fixing enzyme	RuBP carboxylase, which is inefficient	PEP carboxylase, which is very efficient	RuBP carboxylase, working efficiently because carbon dioxide concentration is high
First product of photosynthesis		A three carbon acid, phosphoglyceric acid	A four carbon acid, e.g., oxaloacetate
Leaf anatomy		Only one type of chloroplast	'Kranz' anatomy, i.e., two types of cell, each with its own type of chloroplast.
Efficiency		Less efficient photosynthesis than C_4-plants. Yield usually much lower	More efficient photosynthesis than C_3-plant but use more energy. Yields usually much higher

Some Plant Families Having CAM Species

Family	Familiar Example	Family	Familiar Example
Agavaceae	*Agave, Yucca*	Labiatae	Mints
Aizoaceae	Ice plants	Liliaceae	Lilies
Asclepiadaceae	Milkweeds	Orchidaceae	Orchids
Asteraceae	*Aster*, daisiers	Oxalidaceae	*Oxalis*
Bromeliaceae	Bromeliads	Piperaceae	Peppers, *Pereromia*
Cactaceae	Cacti	Poolpodiaceae	(A fern)
Crassulaceae	Stone crops, sedums	Polrtulaceae	Purslanes
Didiereaceae	(No common, familiar example)	Vitaceae	Grapes
Euphorbiaceae	Spurges	Welwitschiaceae	(A gymnosperm)
Geraniaceae	Geraniums		

❑ Translocation of Food

- **Food, primarily sucrose is transported by vascular tissue phloem from source (i.e., leaf) to a sink (i.e., part that needs or stores the food).**
- **The directions of movement in phloem can be upwards or downwards, i.e., bidirectional in contrast to xylem, where the movement is always unidirectional, i.e., upwards. Hence, phloem sap is mainly water and sucrose but other sugars, hormones and amino acids are phloem.**
- **The most accepted theory for translocation of sugars from source to sink is Munch mass flow theory or pressure flow theory or turgor flow supported by Crafts.**
- **In leaves (i.e., source), osmotic concentration remain always high due to photosynthesis whereas, in roots (i.e., sink), osmotic concentration remains low, consequently mass flow of organic food continues from leaves to roots (i.e., along a gradient of turgor pressure).**

- **In angiosperms synthesis of chlorophyll occurs in presence of light.**
- **The source of energy for carbon assimilation is sunlight.**
- **In photosynthesis chlorophyll serves as energy convertor.**
- **All photosynthetic green plants contain chlorophyll-a.**
- **Photo centres in higher plants are P_{700} and P_{680}.**
- **In the leaves of C_4 plants malic acid formation during CO_2 fixation occurs in the cells of mesophyll.**
- **Optimum temperature for photosynthesis is 20 to 35°C.**
- **The graph showing rate of photosynthesis at different wavelengths of light is called action spectrum.**
- **Red drop occurs in wavelengths of 680 nm.**
- **The wave length of light absorbed by P_r form of phytochrome is 680 nm.**
- **PS-II is concerned with photolysis of water.**
- **Products of light reaction in photosynthesis are ATP and $NADPH_2$.**

- **Photosynthesis is a process in which light energy is converted chemical energy.**
- **Evolution of O_2 in suspension of an isolated chloroplast in light ,in presence of ferric salts is called Hill's reaction.**
- **The first step in photosynthesis is the excitement of an electron of chlorophyll by a photon.**
- **Photosynthesis is a anabolic and reductive reaction.**
- **Non-cyclic photophosphorylation involves Pigment System-I and Pigment System-II.**
- **The first acceptor of electrons from an excited chlorophyll molecule of photosystem-II is quinone.**
- **The electrons liberated from PS-II go to plastoquinone.**
- **High CO_2 compensation point is found in C_3 – plants.**
- **During photosynthesis CO_2 gets reduced and water gets oxidized.**
- **In C_4- pathway CO_2 fixation occurs in chloroplast of mesophyll cells.**

- **Discovery of Emerson effect has clearly shown the existence of two distinct photochemical reactions or processes.**
- **NADP is converted into $NADPH_2$ in non-cyclic photo-phosphorylation.**
- **ATP formation during photosynthesis is known as photophosphorylation.**
- **Photophosphorylation is a process in which light energy is converted into chemical energy by production of ATP.**
- **Fixation of one molecule of CO_2 through Calvin cycle requires 3 ATP and 2 $NADPH_2$ molecules.**
- **Calvin cycle turns 6 times to yield one molecule of glucose.**
- **Calvin cycle occurs in chloroplast.**
- **The C_4 – plants differ from C_3 – plants in the substance that accepts CO_2 during assimilation.**
- **Carbon dioxide joins the route of photosynthesis during dark reaction.**
- **Kranz anatomy is peculiar feature of C_4- plants.**

- **During photosynthesis oxygen is liberated by oxidation of H_2O.**
- **Photosynthetic Active Radiation (PAR) has 400 to 700 nm range of wavelength.**
- **CO_2 acceptor in C_3-plants is phosphoenol pyruvate.**
- **In dark reaction first stable product of photosynthesis in C_3-plants is 3-phosphoglyceric acid.**
- **Solarisation is a process in which destruction of chlorophyll and ultimate death of living organism occurs.**
- **Warburg effect is decreased rate of photosynthesis at higher concentration of CO_2.**
- **In photosystem-I, the first electron acceptor is an iron-sulphur protein.**
- **Assimilatory power in photosynthesis refers to ATP + $NADPH_2$**
- **'Red drop' in photosynthesis in green algae refers to decrease in the rate of photosynthesis in red light greater than 680nm.**

- **Kranz anatomy is characteristic of leaf.**
- **RUBISCO (RuBP carboxylase/oxygenase) a protein, which comprises 5% of total chloroplast protein.**
- **Action spectrum of photosynthesis was described by Engelmann in 1883.**
- **The translocation of organic solutes in sieve tube members is supported by mass flow involving a carrier and ATP.**
- **Which of the following statements is not correct for C_4-plants These are less efficient for photosynthesis.**
- **Downward movement of organic and inorganic solutes from leaves occurs through phloem by mass flow.**
- **The chlorophylls absorb visible light in the region of the following wavelengths 400 to 500 nm and 600 to 700 nm**
- **Wavelength of light, which is maximum absorbed by chlorophyll is 400 to 510 nm.**
- **Photosynthetic enhancement with flashing light was first observed by Emerson and Arnon.**

- **During dark reaction for fixation of carbon, the three carbon atoms of each molecule of 3-phosphoglyceric acid (PGA) are derived from RuBP+CO_2.**
- **During light reaction of photosynthesis, which of the following phenomenon is observed during cyclic phosphorylation as well as non-cyclic phosphorylation Formation of ATP.**
- **Compensation point is the value of a factor where, there is photosynthesis equal to rate of respiration.**
- **Some anaerobic photosynthetic bacteria used other hydrogen donors of H_2S instead of water because they can not tolerate oxygen.**
- **Phytochrome are regulators synthesized by plants and influencing physiological process.**
- **The transport of sugars and other organic molecules within a plant is called translocation.**

- **A lot of starch is stored in the potatoes, which are underground. This is made possible by the activity of enzymes, which convert starch to sugar and sugar back to starch after it has reached the potato.**
- **The direction of the conduction of food through phloem is from leaves to roots.**
- **The movement of solutes in the phloem is mainly basipetal.**
- **Photosynthesis in C_4- plants is relatively less limited by atmospheric CO_2 levels because the primary fixation of CO_2 is mediated via PEP carboxylase.**
- **Translocation of carbohydrates or sugars in the flowering plants occurs in the form of sucrose.**
- **Mass flow hypothesis was first described by Munch.**
- **The term apoplast and symplast were coined by Munch.**
- **Supply ends in transport of solutes are green leaves.**
- **The food stored in the ripening fruit is derived from farthest leaves.**

- **The protoplasmic streaming hypothesis for food translocation has not been accepted because mature sieve elements do not show streaming.**
- **Chlorophyll in chloroplasts is located in grana.**
- **Starch is insoluble in water yet it is accumulated in large quantities in potato because it is translocated in the form of sugar from the leaves to the tuber.**
- **With the increase in light intensity the translocation rate increases more in the shoot than roots.**
- **The elements necessary for translocation of sugars in plants is Boron.**
- **As compared to a C_4-plant 12 additional molecules of ATP are needed for net production of one molecule of hexose sugar by C_4-plant.**
- **The chief function of sieve tube element is to translocate the organic materials from source to sink.**

- **The translocation of organic solutes in sieve tube members is supported by mass flow involving a carrier and ATP.**
- **Phloem loading is pouring of sugar into phloem or symplastic operation transporting raffinose or stachyose in addition to sucrose.**
- **Phenomenon which converts light energy into chemical energy is known as photosynthesis.**
- **In the C_4 -plants , C_4 cycle occurs in the mesophyll cells and C_3 -cycle occurs in bundle sheath cells, whereas in CAM plants C_4 and C_3 -cycles occur in the mesophyll cells only.**
- **3 ATP and 2 $NADPH_2$ molecules are used for fixing one molecule of CO_2.**
- **During formation of 1,3 diphosphoglyceric acid from 3-Phosphoglyceric acid the phosphate donor is ATP.**
- **In C_3 – plants the first stable product of photosynthesis during the dark reaction is 3-phosphoglyceric acid.**

- **12 molecules of inorganic phosphate molecules are generated in Calvin cycle in formation of PGAL.**
- **RuBP carboxylase enzyme catalyses the carboxylation reaction between CO_2 and ribulose 1-5 diphosphate.**
- **In case of C_4 –plants Rubisco enzyme fixes the CO_2 released during decarboxylation of malate.**
- **Photosynthesis consists of essentially two biological reaction systems, one followed by the other the second of these systems fixes CO_2.**
- **In blue-green algae, photosystem-II contains important pigment concerned with photolysis of water , it is phyocyanin.**
- **The synthesis of ATP in both photosynthesis and respiration is essentially an oxidation process, in which energy is utilized from the electron.**
- **Plants adapted to low light intensity have larger photosynthetic unit size than the sun plants.**

- **Ruben and Kamen confirmed that O2 comes from water during photosynthesis.**
- **Photosynthetic reaction is as**

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

- **In pigment system-I the carrier that picks up electrons from P_{700} is Fe-S protein.**
- **When a cell converts light energy into chemical energy then the reaction will be**

$$ADP + iP = ATP$$

- **A photosynthesizing organism which does not release molecular oxygen during the process is green sulphur bacterium.**
- **Photosynthetic bacteria does not evolve oxygen during photosynthesis.**
- **The carrier of CO_2 from mesophyll cells to bundle sheath cell is malic acid.**
- **Last reaction in Calvin cycle is regeneration of RuBP.**

Thank You…