DAY FIFTEEN

Photosynthesis

Learning & Revision for the Day

- Site of Photosynthesis
- Pigments Involved in Photosynthesis
- Spectrum of Light
- Photosystems
- Mechanism of Photosynthesis
- Photorespiration (C_2-Cycle)
- Factors Affecting Photosynthesis

Photosynthesis is a means of autotrophic nutrition. It is the formation of carbohydrates from CO_2 and H_2O with the help of sunlight in the presence of chlorophyll, contained in the green parts of plants. It is an anabolic process.

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

- **Ruben** and **Kamen** (1941) proved that the source of evolved oxygen (O_2) in the photosynthesis is water (H_2O) and not carbon dioxide (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 molecular oxygen (O_2), whereas in purple and green sulphur bacteria, H_2S is the hydrogen donor and sulphur or sulphate is the oxidation product.
- Cyanobacteria are first photosynthetic organisms evolved during the course of evolution.
- In **bacterial photosynthesis** (e.g. green sulpher bacteria), H_2, H_2S and other compounds are employed as hydrogen donor instead of water. Therefore, it occurs without evolution of oxygen, hence is anoxygenic.
- Bacteria have only one pigment system which is similar to photosystem-I (PS-I).
- The pigment containing structures such as thylakoids in green plants are not found in cyanobacteria (blue-green algae) and photosynthetic bacteria (prokaryotes). They are scattered in cytoplasm.
- In these organisms, 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 freshwater. Only about 0.2% of the sunlight energy falling on earth is utilised by photosynthetic organisms.

Site of Photosynthesis

- In eukaryotes, photosynthesis takes place in chloroplasts present in cytoplasm, which vary in numbers from one (e.g. *Chlorella*) to about 100 (e.g. palisade mesophyll cells).
- Chloroplasts are visible under light microscope (3-10 μm diameter). They are covered by two membranes each of 9-10 nm thickness.
- Internally, a chloroplast contains **matrix** or **stroma** and **thylakoids**.
- Thylakoids are the chlorophyll containing flattened membranous sacs present in the stroma.
- At some places, 20-50 thylakoid discs get aggregated to form granum.
- Thylakoids are the site of light reaction, whereas the stroma is the site of dark reaction.

Pigments Involved in Photosynthesis

The most common photosynthetic pigments in higher plants and green algae are as follows

1. **Chlorophyll-*a*** is an essential pigment in photosynthesis because it can convert light energy into chemical energy (ATP).
    - It is also called as universal photosynthetic pigment or primary photosynthetic pigment.
    - The basic structure of all chlorophyll molecules is a porphyrin system, in which four pyrrole (tetrapyrrole) rings are linked together by methane groups to form a ring system.
2. **Carotenoid** is a group of accessory photosynthetic pigments of yellowish or reddish colour.
    - They are of two types, i.e. carotenes (e.g. β-carotene) and xanthophylls (lutein and 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.
3. **Phycobilins** are water soluble, open tetrapyrrole pigments found in red algae and blue-green algae.

    These are of three types, i.e. phycocyanin (blue), allophycocyanin (blue) and phycoerythrin (red).
4. Pigments like chlorophyll-*b*, carotenoid, etc., act as accessory pigments because they collect and transfer light energy to chlorophyll-*a* for photosynthesis, and also protects chlorophyll from its photo-oxidation.

Spectrum of Light

- Light is a narrow band of radiant energy within the continuous electromagnetic spectrum of radiation emitted by the sun. Visible light ranges from 390-760 nm.
- **Photosynthetically Active Radiation** (PAR) is the region of wavelength in which photosynthesis takes place normally, which is approximately 50% of the total incidented solar radiation.
- It ranges from 400-700 nm and plants capture only 2-5% of the total PAR.
- **Absorption spectrum** is the graphic representation or the curve showing the various wavelengths of light absorbed by a pigment.
- Chlorophyll absorbs 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 the actual rate of photosynthesis with respect to the wavelength of light absorbed.
- It is closely related to the absorption spectra of chlorophyll-*a* and *b* and is measured in terms of O_2 evolved at different light wavelengths.

Emerson-Enhancement Effect

- In 1950, Robert Emerson and his 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 parts of the spectrum. The phenomenon was celled as **red-drop**
- Emerson's experiments gave conclusive idea that process of photosynthesis involves two light reactions, one is carried by short wavelength absorbing form of chlorophyll-*a* and other by accessory pigments including a long wavelength absorbing form of chlorophyll-*a*. This led to the idea of two photosystems.

Photosystems

These are the functional and structural units of protein complexes involved in photosynthesis. Each photosystem has a reaction centre which contains a special chlorophyll-*a* molecule and is different in both the photosystems.

1. **Photosystem-I** (PS-I) is present in stroma thylakoids and non-appressed part of granal thylakoids. Its reaction centre has a peak absorption at 700 nm, called $\mathbf{P_{700}}$.
    - It can perform cyclic photophosphorylation independently.

- PS-I is active both in red and far-red light and it carries out reduction of NADP.
- PS-I is having pigments, chl-*a* 660, chl-*a* 670, chl-*a* 680, chl-*a* 690, chl-*a* 700 and carotenoids.
- It consists of photocentre, Light Harvesting Complex [LHC-I] and some electron carriers.

2. **Photosystem-II** (PS-II) is located in the appressed part of the grana thylakoids.
   - The PS-II is inactive in far-red light (beyond 680 nm). Its reaction centre is $\mathbf{P_{680}}$.
   - It picks up electrons emitted during photolysis of water and performs non-cyclic photophosphorylation or the Z-scheme of light reaction.
   - PS-II is having pigments chl-*b* 650, chl-*a* 660, chl-*a* 670, chl-*a* 678, chl-*a* 680 and phycobilins.
   - It consists of photocentre, oxygen evolving complex, Light Harvesting Complex (LHC-II) and some electron carriers.

Mechanism of Photosynthesis

The two major steps of photosynthesis are as follows

1. Light Reaction or Photochemical Phase

- It takes place only in the presence of light in the grana portion of the chloroplast.
- Light is trapped by photosynthetic pigments present in the grana thylakoids. The light reaction occurring in thylakoid completes in three stages described below

(i) Photoexcitation of Chlorophyll-a

- The process of light reaction starts when photosynthetic pigments of both PS absorb light energy.
- Then their antenna molecules transfer the absorbed energy to the reaction centre. This makes the reaction centre of both PS highly energised or photoexcited and as a result, it emits a pair of electrons.
- The electrons ejected by PS are accepted by primary electron acceptor Ferredoxin Reducing Substance (FRS). It passes them into an Electron Transport System (ETS). During non-cyclic photophosphorylation, it leads to reduction of NADP into NADPH + H^+, while during both cyclic and non-cyclic photophosphorylation, it results in the formation of ATP from ADP and inorganic phosphate. Thus, the flow of electrons through ETS is linked to photophosphorylation.

(ii) Photolysis of Water

- In this process, water splits into H^+, [O] and electrons. The two electrons obtained from the photolysis of one water molecule is passed on to PS-II.
- An oxygen evolving complex is located on the inner side of thylakoid membrane. Photolysis of water also requires minerals such as Mn^{2+}, Cl^- and Ca^{2+}.
- The protons and oxygen formed in this process are released within the lumen of thylakoids and O_2 is evolved as byproduct. Whole reaction is summerised as given below

$$2H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} 4H^+ + 4\,e^- + O_2 \uparrow$$

- The photolysis of water or photochemical oxidation of water was first described by Van Niel in 1931. Later on it was demonstrated by R Hill 1937. Therefore, it is also known as **Hill reaction**.

(iii) Photophosphorylation

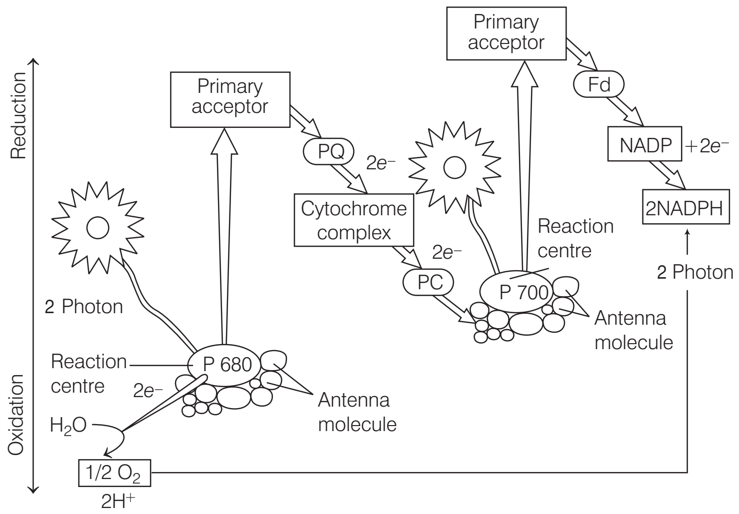
It is the light driven or light energised synthesis of ATP molecules. It was discovered by Arnon *et al* in 1954.
Photophosphorylation reactions are of two types

(a) **Non-cyclic photophosphorylation** When ATP formation is coupled to a non-cyclic transfer of electrons, it is called as non-cyclic photophosphorylation.

- During this process, electrons are not cycled back to the P_{680}, i.e. PS-II. They are used in the reduction of NADP to $NADPH_2$. It also utilises water to release oxygen and hydrogen (photolysis).
- The electrons emitted by reaction centre P_{680} are first accepted by an electron acceptor PQ (plastoquinone).
- These electrons are then transferred through electron carriers like cytochrome-b_6, cytochrome-f and finally of plastocyanin.
  Cytochrome, plastoquinone and plastocyanin are the important electron carriers. They are described below
  - **Cytochromes** These are small proteins that contain a cofactor, haem, having an Fe-atom. Cytochromes are intrinsic membrane proteins of thylakoid membranes.
  - **Plastoquinones** (PQ) They transport electrons over short distance within a membrane. Their long hydrocarbon tail is hydrophobic, thus they dissolve easily into the lipid component of the chloroplast membrane.
  - **Plastocyanin** (PC) It is a small protein that carries electrons with the help of copper.
- From plastocyanin, electrons are finally transferred to the reaction centre of PS-I.
- PS-I also receives photons of light and becomes photoexcited. Now, it expels electrons that enters the ETS. Finally the $NADP^+$ present in stroma receive electrons through ETS.
  It also receives protons *via* photolysis of water. Thus, it gets reduced into $NADPH + H^+$

$$2NADP + 4e^- + 4H^+ \longrightarrow 2NADPH_2$$

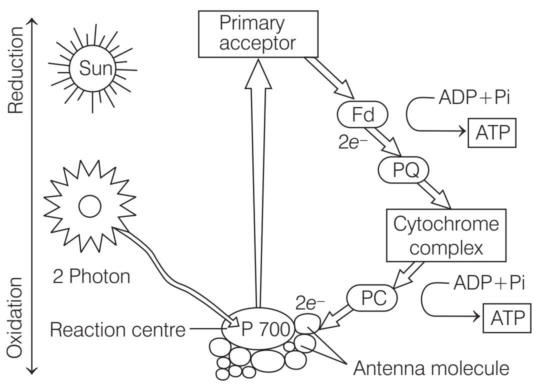
- Due to the transfer of electrons, energy is released during non-cyclic transfer. This energy is utilised to form ATP from ADP and iP. ATP formation occurs by chemiosmosis.
- The process is also known as Z-scheme, due to the characteristic flow of electrons across the two photosystems.



Non-cyclic photophosphorylation

(b) **Cyclic-photophosphorylation** The process of formation of ATP from ADP + iP *via* a cyclic flow of electrons in photosystem-I is known as cyclic photophosphorylation. It is called, so because in this process, the donor and final acceptor is same, i.e. P_{700}. This occurs in low light intensity, when CO_2 fixation is inhibited.

- The energy rich electrons from the PS-I, i.e. P_{700} are first accepted by primary electron acceptor, FRS and transferred to Fd (Ferredoxin). From Fd, the electrons are transferred to cytochrome-b_6 (and not to NADP), cytochrome-f and then to PC.
- From PC, the electrons are finally returned back to the reaction centre of PS-I, i.e. P_{700}. In this process, 2 molecules of ATP are synthesised, and no reduction of NADP to NADPH + H^+ takes place.



Cyclic photophosphorylation

Chemiosmotic Hypothesis

- It explains the mechanism of how actually ATP molecule is synthesised in the chloroplast.
- In brief, chemiosmosis requires a membrane, a proton pump, proton gradient and ATPase. The photolysis of water (inside lumen of thylakoid) and movement of hydrogen ions (H^+) from stroma to lumen of thylakoid during electron transport system as well as reduction of $NADP^+$ to NADPH $_2$, creates a gradient or a high concentration of protons within the thylakoid lumen.
- ATPase has a channel that allows diffusion of protons back across the membrane leading to the breakdown of the gradient.
- This releases enough energy to activate ATPase enzyme that catalyses the formation of ATP.
- This ATP is used immediately in biosynthetic reaction taking place in the stroma responsible for fixing CO_2 and synthesis of sugars.
- The products of light reactions are ATP, NADPH and O_2. Of these, O_2 diffuses out of the chloroplast, while ATP and NADPH are used to derive the processes leading to the synthesis of food, i.e. sugar.

2. Dark Reaction or Biosynthetic Phase

- The biosynthetic phase of photosynthesis does not directly depend on the presence of light but is dependent on the products of the light reaction, i.e. ATP and NADPH, besides CO_2 and H_2O.
- Dark reaction was discovered by **FF Blackman** (1905) and later on studied in detail by **Calvin, Benson** and **J Bassham** and for this work they were awarded Nobel Prize (1961).
- Dark reaction is purely enzymatic reaction, which occurs in stroma of chloroplast.
- Originally this was also known as carbon-fixation cycle.
- There are two main pathways for the biosynthesis or dark phase, i.e. Calvin cycle or C_3 cycle and C_4 oxaloacetic acid cycle.
- A third pathway is CAM metabolism which is intermediate between C_3 and C_4 cycles.
- The plants exhibiting C_3 and C_4 cycles are called C_3-plants and C_4-plants, respectively.
- Grass *Alloteropsis semi-alata* has both C_3 and C_4 ecotypes (ecological variants).

Calvin Cycle or C_3 Pathway

- It is found in all photosynthetic plants including both C_3 and C_4-plants.
- **Melvin Calvin** used radioactive ^{14}C to study photosynthesis in algae to discover that the first CO_2 fixation product was a 3-carbon compound 3-phosphoglyceric acid.
- The path of carbon assimilation was given by **Calvin, Benson** and **Bassham** (1949).

Calvin cycle involves three steps

(i) **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 (Ribulose-1, 5-biphosphate).

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 RuBisCO.

(ii) **Reduction** This is a series of reactions that lead to the formation of glucose.

This steps involve utilisation of 2 molecules of ATP for phosphorylation and two of NADPH for reduction per CO_2 molecule fixed.

(iii) **Regeneration** steps require one ATP for phosphorylation to form CO_2 acceptor molecule RuBP which is crucial, if the cycle is to continue uninterrupted. 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, 18 ATP and 12 $NADPH_2$ are required for the synthesis of one molecule of hexose sugar. Thus, overall reaction is expressed as:

$$6\ RuBP + 6CO_2 + 12NADPH + 12H^+ + 18ATP + 6H_2O \longrightarrow 6\ RuBP + Glucose + 12NADP^+ + 18ADP + 18iP$$

Almost 85% of plant species are C_3-plants, including cereals (e.g. barley, rice, oat and wheat) groundnut, sugarbeet, cotton tobacco, spinach, soybean, most trees and loan grasses, etc.

C_4 Pathway or Hatch-Slack Cycle

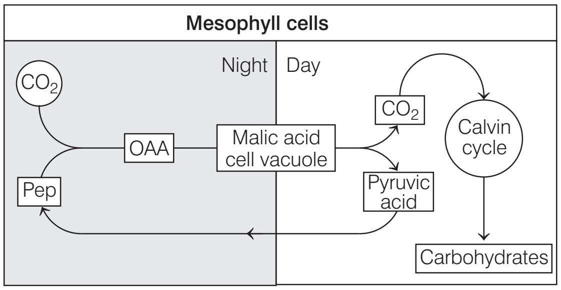
- It was worked out by Hatch and Slack (1965), thus also known as Hatch and Slack pathway.
- The first product of CO_2-fixation in C_4-pathway is a C_4 acid, i.e. Oxalo Acetic Acid (OAA).
- It occurs in plants like maize, sugarcane, sunn plant, etc.
- In these plants, there is a special **Kranz anatomy**, in which, mesophyll cells are adjacent to bundle sheath cells containing large chloroplasts.
- All known C_4-plants are angiosperms.
- CO_2 combines with 3-carbon Phosphoenol Pyruvate (PEP) in the 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.
- Here, 30 ATP and 12 $NADPH_2$ are required for the formation of one molecule of hexose sugar (glucose).

Differences between C_3 and C_4-plants

Characteristics	C_3-plants	C_4-plants
Representative species	Most of the crop plants, e.g. cereals, tobacco and beans	Maize and sugarcane
Photorespiration	High	Negligible
Temperature optimum	20–25°C	30–45°C
CO_2 compensation point	25-100 ppm	0–10 ppm
Chloroplast	One type (granal only)	Two types (granal and agranal)
Carbon dioxide fixation	Occurs once	Occurs twice, first in the mesophyll cells, then in bundle sheath cells
Carbon dioxide acceptor	RuBP, a 5C compound	PEP, a 3C compound
Carboxylase enzyme	RuBisCO	PEPcase, RuBisCO
First product of photosynthesis	A three carbon acid, phosphoglyceric acid.	A four carbon acid, e.g. oxaloacetate.
Leaf anatomy	No distinct bundle sheath, Kranz anatomy absent.	Kranz anatomy present .
Efficiency	Less efficient photosynthesis than -plants. Yield is usually much lower.	More efficient photosynthesis than -plants, but use more energy. Yield is usually much higher.

CAM (Crassulacean Acid Metabolism) Pathway

- This pathway is mostly present in the succulent xerophytes, such as the members of Crassulaceae, Euphorbiaceae, etc.
- In this process, during night time, the stomata remain open and CO_2 enters through it, which is accepted by OAA and converted into malic acid. The schematic representation of CAM pathway is as follows



CO_2 fixation in CAM plants

- At night stomata are open and CO_2 is fixed by the action of PEP (Phospho Enol Pyruvic acid) carboxylase (shown by **asterisk**) malic acid is stored in the cell vacuole.
- During day the stomata are closed, CO_2 is released from malic acid and fixed by Calvin cycle.
- During daytime the malic acid produced at night results into production of both pyruvic acid and CO_2 on decarboxylation. The pyruvic acid so produced is recycled back, so produce PEP, while CO_2 enter into Calvin cycle.

Photorespiration (C_2 Cycle)

- It is a special type of respiration shown by many green plants, when they are exposed to light. It was discovered by **Dicker** and **Tio** (1959) in tobacco.
- The site for photorespiration is chloroplast. Peroxisome is required to complete the process.
- At high temperature and high oxygen concentration, RuBP carboxylase functions as oxygenase and instead of fixing carbon dioxide it oxidises ribulose 1, 5-biphosphate to produce phosphoglyceric acid and phosphoglycolate.

$$\text{RuBP} + O_2 \xrightarrow[\text{Oxygenase}]{\text{RuBP}} \text{PGA} + \text{Phosphoglycolate}$$

- Phosphoglycolate is hydrolysed to form glycolate that usually passes into peroxisomes of the mesophyll cells and forms glyoxalate.
- Glyoxalate is now converted into an amino acid glycine. This is a transamination reaction.
- The glycine formed in peroxisomes migrates into mitochondria where 2 molecules of glycine react to form one molecule of another amino acid serine with the liberation of CO_2 (post-illumination burst of CO_2 and photorespiration) and also NH_2.
- This reaction is catalysed by the enzyme serine hydroxymethyl transferase.
- Serine can further be deaminated to form PGA which passes into chloroplast for the synthesis of photosynthetic products as well as photorespiration.
- Since, photorespiration involves the synthesis of two carbon compounds, it is also called as **C_2-cycle** (glyoxylate and glycine are 2-C compounds). C_2 cycle is also known as **glycolate metabolism**.

$$\text{Phosphoglycolate} + H_2O \xrightarrow{\text{Phosphatase}} \text{Glycolate} + H_3PO_4$$

$$\text{Glycolate} + O_2 \xrightarrow{\text{Oxidase}} \text{Glyoxylate} + H_2O_2$$

$$2\,H_2O_2 \xrightarrow{\text{Catalase}} 2H_2O + O_2$$

$$\text{Glyoxylate} + \text{Glutamate} \xrightarrow{\text{Transaminase}} \text{Glycine} + \alpha\text{-ketoglutarate}$$

$$2\,\text{Glycine} + \alpha\text{-ketoglutarate} + NAD^+ \longrightarrow \text{Serine} + \text{Glutamate} + NADH + CO_2 \uparrow$$

$$\text{Serine} + NADH + ATP \longrightarrow PGA + NH_3 + NAD^+ + ADP$$

- Since C_4-plants lack the process of photorespiration, the productivity and yields in these plants are better than those in C_3-plants.
- This happens because the OAA from the mesophyll cells of the C_4-plants, tends to be broken down in bundle sheath cells releasing CO_2.
- Hence, the RuBP carboxylase enzyme functions more as carboxylase, minimising the role of oxygenase.

Factors Affecting Photosynthesis

Many factors affect the rate of photosynthesis which are as follows

1. Atmospheric Concentration of CO_2

It is 0.03% (300ppm). Increase in its 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.

2. Light

- 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.
- Very high light intensity decreases the rate of photosynthesis and this phenomenon is called as **solarisation**.
- It may be due to the photoinhibition and photooxidation.
- In case of C_4-plants, saturation point is not reached even in full sunlight.

3. Temperature

- It 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 and in some conifers, it occurs even at **–35**°C.
- When temperature is increased from minimum to optimum, the rate of photosynthesis doubles for every 10°C rise in temperature.

4. Rate of Respiration

- Usually, in the mornings and evenings, the rate of respiration is approximately equal to the rate of photosynthesis, there shall not be any apparent gaseous exchange.
- The O_2 evolved during photosynthesis will be utilised in respiration and CO_2 evolved during respiration will be used in photosynthesis. This stage is theoretically called **compensation point**.
- 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-plants. Above 21%, there is reduction in photosynthesis. This effect is called as **Warburg effect.**
- This is due to O_2 which is a strong quencher of excited state of chlorophyll and high concentration of O_2 that converts RuBP carboxylase to RuBP oxygenase.

5. Organic and Inorganic Nutrients

Sulphur dioxide, ozone, chlorofluorocarbon, 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 chloroplast also reduces the rate of photosynthesis.

Law of Limiting Factor

- In 1905, **FF Blackman** proposed principle or law of limiting factors.
- According to this law, 'when a process is conditioned as to its rapidity 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).

DAY PRACTICE SESSION 1

FOUNDATION QUESTIONS EXERCISE

1 Photosynthesis is a mode of

(a) Saprotrophic nutrition
(b) Mixtrophic nutrition
(c) Autotrophic nutrition
(d) Heterotrophic nutrition

2 Which evidence confirmed that O_2 released in photosynthesis comes from water?

(a) Isolated chloroplast in water releases O_2 if supplied potassium ferrocyanide (reducing agent)
(b) Photosynthetic bacteria use H_2S and CO_2 to make carbohydrates, H_2O and sulphur
(c) Isotopic O_2 supplied as H_2O appears in the O_2 release in photosynthesis
(d) All of the above

3 In green sulphur bacteria, the hydrogen donor is

(a) H_2O (b) H_2S
(c) H_2SO_4 (d) HNO_3

4 Oxygen is not produced during photosynthesis by
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(a) *Cycas* (b) *Nostoc*
(c) Green sulphur bacteria (d) *Chara*

5 Some anaerobic photosynthetic bacteria use other hydrogen donors like H_2S instead of water because

(a) they cannot tolerate oxygen
(b) other donors are freely available in the growth medium
(c) other donors need less energy input
(d) other donors yield more glucose molecules

6 In bacterial photosynthesis,

(a) PS-I is present
(b) PS-II is present
(c) both PS-I and PS-II are present
(d) None of these is present

7 Chemosynthetic bacteria obtain energy from

(a) sun (b) inorganic chemicals
(c) organic substances (d) infra-red rays

8 Which photosystem is exhibited by photosynthetic bacteria?

(a) Pigment system-I (b) Pigment system-II
(c) Both (a) and (b) (d) None of these

9 Photosynthetic pigments in chloroplast lie embedded in

(a) chloroplast envelope (b) plastoglobule
(c) matrix (d) thylakoids

10 Functional unit of photosynthesis is known as
(a) electron (b) photon
(c) chlorophyll (d) quantasome

11 In eukaryotes, chloroplasts vary in numbers. The organism having only one chloroplast is
(a) *Chlorella* (b) *Nostoc*
(c) *Oscillatoria* (d) *Sargassum*

12 Photosynthetically active radiation is represented by the range of wavelength
(a) 340-450 nm (b) 400-700 nm
(c) 500-600 nm (d) 400-950 nm

13 The chlorophylls absorb visible light in the region of the following wavelengths
(a) 400-500 nm
(b) 600-800 nm
(c) 400-500 nm and 600-700 nm
(d) None of the above

14 The graph showing rate of photosynthesis at different wavelength of light is called
(a) absorption spectrum (b) action spectrum
(c) Both (a) and (b) (d) None of these

15 Discovery of Emerson's effect has clearly shown the existence of
(a) photorespiration
(b) photophosphorylation
(c) light and dark reaction in photosynthesis
(d) two distinct photochemical reactions or processes

16 In which part of the cell does the light reaction occur?
(a) Grana portion of chloroplast
(b) Stroma portion of chloroplast
(c) Inside the two membrane coverings
(d) Lysosome

17 Which of the following is not a product of light reaction of photosynthesis? ➞NEET 2018
(a) NADPH (b) NADH
(c) ATP (d) Oxygen

18 In photosystem-I, the first electron acceptor is
(a) cytochrome
(b) plastocyanin
(c) an iron-sulphur protein
(d) ferredoxin

19 Pigment acting as a reaction centre during photosynthesis is
(a) carotene (b) phytochrome
(c) P_{700} (d) cytochrome

20 Photosystem-II occurs in
(a) stroma (b) cytochrome
(c) grana (d) mitochondrial surface

21 The first acceptor of electrons from an exicted chlorophyll molecule of photosystem-II is
(a) cytochrome (b) iron-sulphur protein
(c) ferredoxin (d) quinone

22 Photophosphorylation is a process in which
(a) light energy is converted into chemical energy by production of ATP
(b) glutamic acid is formed
(c) 2 PGA is formed
(d) None of the above

23 $NADP^+$ is reduced to NADPH in
(a) PS-I
(b) PS-II
(c) Calvin cycle
(d) Non-cyclic photophosphorylation

24 A photosynthesising plant is releasing ^{18}O more than the normal. The plant must have been supplied with
(a) O_3 (b) H_2O with ^{18}O
(c) CO_2 with ^{18}O (d) $C_6H_{12}O_6$ with ^{18}O

25 Non-cyclic photophosphorylation involves
(a) PS-I (b) PS-II
(c) Both (a) and (b) (d) None of these

26 Which one occurs both during cyclic and non-cyclic modes of photophosphorylation?
(a) Involvement of both PS-I and PS-II
(b) Formation of ATP
(c) Release of O_2
(d) Formation of NADPH

27 The site of the dark reaction of photosynthesis is
(a) grana (b) thylakoid
(c) stroma (d) intergranary fibres

28 Carbon dioxide joins the photosynthetic pathway in
(a) PS-I (b) PS-II
(c) light reaction (d) dark reaction

29 All the reactions from the reduction of CO_2 to the formation of sugars are included in
(a) light reaction (b) photolysis
(c) dark reaction (d) Hill reaction

30 RuBisCO is an enzyme for
(a) CO_2 fixation in dark reaction
(b) photorespiration
(c) regeneration of RuBP
(d) photolysis of water

31 Stroma in the chloroplasts of higher plants contains
(a) light-independent reaction enzymes
(b) light-dependent reaction enzymes
(c) ribosomes
(d) chlorophyll

32 Dark reaction in photosynthesis is called so because
(a) it can occur in dark also
(b) it does not directly depend on light energy
(c) it cannot occur during day light
(d) it occurs more rapidly at night

33 Calvin cycle occurs in which of the following organelles?
(a) Mitochondria (b) Chloroplast
(c) Cytoplasm (d) Glyoxysomes

34 Which algae were used by Calvin for his experiments to trace the carbon path?
(a) *Chlorella* and *Chlamydomonas*
(b) *Chlorella* and *Scenedesmus*
(c) *Chlorococcum* and *Chlorella*
(d) *Chlorococcum* and *Scenedesmus*

35 The first carbon dioxide acceptor in C_4-plants is
(a) phosphoenol-pyruvate
(b) ribulose 1, 5-diphosphate
(c) oxalo acetic acid
(d) phosphoglyceric acid

36 Which technique has helped in investigation of Calvin cycle?
(a) X-ray crystallography
(b) X-ray technique
(c) Radioactive isotope technique
(d) Intermittent light

37 How many turns of Calvin cycle yield one molecule of glucose?
(a) 8 (b) 2
(c) 6 (d) 4

38 PGA as the first CO_2-fixation product was discovered in photosynthesis of
(a) bryophyte (b) gymnosperm
(c) angiosperm (d) alga

39 C_4-plants are found among
(a) dicots
(b) monocots
(c) Both (a) and (b)
(d) in family Poacae (Gramineae)

40 In the leaves of C_4-plants, malic acid formation during CO_2-fixation occurs in the cells of
(a) mesophyll (b) bundle sheath
(c) phloem (d) epidermis

41 First carbon-fixation in C_4-pathway occurs in chloroplasts of
(a) palisade tissue (b) spongy mesophyll
(c) bundle sheath (d) guard cells

42 Fixation of one CO_2 molecule through Calvin cycle requires
(a) 1 ATP and 2 $NADPH_2$
(b) 2 ATP and 2 $NADPH_2$
(c) 3 ATP and 2 $NADPH_2$
(d) 2 ATP and 1 $NADPH_2$

43 Which enzyme is most abundantly found on earth?
(a) Catalase (b) RuBisCO
(c) Nitrogenase (d) Invertase

44 Identify the incorrect statement.
(a) Kranz anatomy is present in C_3- plants
(b) Maize/Corn is a C_4-plant
(c) C_4 cycle is also called HSK pathway
(d) CO_2-fixation occurs twice in C_4-plants

45 When CO_2 is added to PEP, the first stable product synthesised is
(a) pyruvate
(b) glyceraldehyde-3-phosphate
(c) phosphoglycerate
(d) oxaloacetate

46 In sugarcane plant, $^{14}CO_2$ is fixed in malic acid, in which the enzyme that fixes CO_2 is
(a) fructose phosphatase
(b) ribulose bisphosphate carboxylase
(c) phosphoenol pyruvic acid carboxylase
(d) ribulose phosphate kinase

47 Which of the following statements is not correct for C_4-plants?
(a) These are less efficient for photosynthesis
(b) These are less efficient for photorespiration
(c) They have Kranz anatomy in their leaves
(d) They use PEP as CO_2 acceptor

48 Which pair is wrong?
(a) C_3–Maize
(b) C_4–Kranz anatomy
(c) Calvin cycle–PGA
(d) Hatch and Slack Pathway–Oxalo acetic acid

49 C_4-plants are more efficient in photosynthesis than C_3-plants due to to the
(a) higher leaf area
(b) presence of larger number of chloroplasts in the leaf cells
(c) presence of thin cuticle
(d) lower rate of photorespiration

50 Advantage that C_4-plants have over C_3-plants is that these
(a) occur in relatively low CO_2 concentration
(b) use more amount of water
(c) occur in relatively low O_2 concentration
(d) has less efficiency of energy utilisation

51 As compared to a C_3-plant, how many additional molecules of ATP are needed for net production of one molecule of hexose sugar by C_4-plants?
(a) 2 (b) 6
(c) 12 (d) 0

52 A process that makes important difference between C_3 and C_4-plants is
(a) transpiration (b) glycolysis
(c) photosynthesis (d) photorespiration

53 The substrate for photorespiration is
(a) ribulose bisphosphate (b) glycolate
(c) serine (d) glycine

54 Which amongst the following is a wastage process?
(a) Respiration (b) Photosynthesis
(c) Movement (d) Photorespiration

55 The cell organelles involved during photorespiration are
(a) chloroplast, mitochondria, Golgi bodies
(b) chloroplast, Golgi bodies, rough endoplasmic reticulum
(c) chloroplast, mitochondria, peroxisome
(d) chloroplast, vacuole, Golgi bodies

56 During photorespiration, the oxygen consuming reaction(s) occur in
(a) stroma of chloroplasts and peroxisomes
(b) grana of chloroplasts and peroxisomes
(c) stroma of chloroplasts
(d) stroma of chloroplasts and mitochondria

57 Which one of the following is wrong in relation to photorespiration?
(a) It is a characteristic of C_3-plants
(b) It occurs in chloroplasts
(c) It occurs in daytime only
(d) It is a characteristic of C_4-plants

58 Photorespiration is favoured by
(a) high O_2 and low CO_2
(b) low light and high O_2
(c) low temperature and high O_2
(d) low O_2 and high CO_2

59 The stomata are kept open during the night in
(a) C_3-plants (b) CAM plants
(c) C_4-plants (d) hybrid plants

60 The metabolic pathway that helps the plants in consuming water is
(a) photosystem-I (b) photosystem-II
(c) Calvin cycle (d) CAM

61 In plants such as *Bryophyllum*, the concentration of organic acid
(a) increases during the day
(b) decreases or increases during the day
(c) increases during night
(d) decreases during anytime of the day

62 The principle of limiting factors was proposed by
(a) Blackman
(b) Hill
(c) Arnon
(d) Liebig

63 Optimum temperature for photosynthesis is
(a) 10-15°C (b) 20-35°C
(c) 25-35°C (d) 35-40°C

DAY PRACTICE SESSION 2

PROGRESSIVE QUESTIONS EXERCISE

1 A very efficient converter of solar energy with net productivity of 2-4 km/m^2 or more is the crop of
(a) wheat (b) sugarcane
(c) rice (d) bajra

2 *Oscillatoria*, a cyanobacteria exhibits
(a) anoxygenic respiration (b) oxygenic respiration
(c) photorespiration (d) CAM

3 Which process is started from phosphoglycolate in C_3 plants?
(a) Respiration (b) Light reaction
(c) Photorespiration (d) Dark reaction

4 Very high intensity of light decreases the rate of photosynthesis. This phenomenon is called
(a) solarisation
(b) compensation point
(c) PAR
(d) Emerson enhancement effect

5 During photosynthesis, both ribulose bisphosphate carboxylase oxygense and phosphoenol pyruvate carboxylase are activated by
(a) Zn^{2+} (b) Mg^{2+}
(c) Ca^{2+} (d) SO_4^{2-}

6 Warburg effect is decreased rate of photosynthesis at
(a) low concentration of CO_2
(b) high concentration of CO_2
(c) high concentration of O_2
(d) None of the above

7 Photochemical reactions in the chloroplast are directly involved in the
(a) formation of phosphoglyceric acid
(b) fixation of carbon dioxide
(c) synthesis of glucose and strach
(d) photolysis of water and phosphorylation of ADP to ATP

8 Chlorophyll-*a* molecule at its carbon atom 3 of the pyrrole ring-II has which one of the following?
(a) Aldehyde group
(b) Methyl group
(c) Carboxyl group
(d) Magnesium

9 Which of the following photosynthetic bacteria has both PS-I and PS-II?
(a) Purple sulphur bacteria
(b) Cyanobacteria
(c) Purple non-sulphur bacteria
(d) Green-sulphur bacteria

10 According to the chemiosmotic hypothesis, ATP synthesis requires
(a) H^+ gradient across the membrane
(b) K^+ gradient across the membrane
(c) PO_4^{3-} gradient across the membrane
(d) Ca^{2+} gradient across the membrane

11 Nine-tenth of all photosynthesis of world (85-90%) is carried out by
(a) large trees with millions of branches and leaves
(b) algae of the ocean
(c) chlorophyll containing ferns of the forest
(d) scientists in the laboratories

12 Which one of the following statements about the events of non-cyclic photophosphorylation is incorrect?
(a) Photolysis of water takes place
(b) Oxygen is released
(c) Only one photosystem participates
(d) ATP and NADPH are produced

13 Synthesis of one molecule of glucose requires
(a) $6CO_2$, 18 ATP and 12 NADPH
(b) $6CO_2$, 12 ATP and 18 NADPH
(c) $6CO_2$, 30 ATP and 12 NADPH
(d) $6CO_2$, 38 ATP and 12 NADPH

14 Photosynthesis in C_4-plants is relatively less limited by atmospheric CO_2 levels because
(a) effective pumping of CO_2 into bundle sheath cells
(b) RuBisCO in C_4-plants has higher affinity for CO_2
(c) four carbon acids are the primary initial CO_2-fixation products
(d) the primary fixation of CO_2 is mediated *via* PEP carboxylase

15 Match the following columns.

Column I		Column II	
A.	C_3-plants	1.	Kranz anatomy
B.	Photolysis of water	2.	Alternative of C_3 and C_4 pathway
C.	C_4-plants	3.	Fruits
D.	CAM	4.	Cereals
		5.	Photochemical phase

Codes

	A	B	C	D		A	B	C	D
(a)	4	5	1	2	(b)	1	2	3	4
(c)	4	5	2	1	(d)	1	3	4	5

16 Which of the following are incorrect?
I. Van Neil showed that photosynthetic bacteria fixed CO_2 in the presence of H_2S.
II. Melvin Calvin discovered C_4-pathway for fixation of CO_2.
III. Park and Biggins discovered quantasome.
IV. Emerson and Arnold used radioactive 18 oxygen and proved that oxygen evolved was part of water.

Codes
(a) I and II (b) II and IV
(c) I, II and III (d) Only IV

17 Match the following columns.

Column I		Column II	
A.	Cytochromes	1.	FF Blackman
B.	Dark reaction	2.	Fixation of CO_2
C.	RuBP	3.	Fixation of nitrogen
D.	Carboxylation	4.	Cofactor haeme
		5.	CO_2 acceptor molecule

Codes

	A	B	C	D
(a)	1	2	3	4
(b)	4	1	5	2
(c)	5	4	2	1
(d)	1	2	4	5

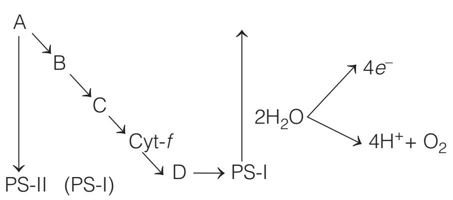
18 Carbohydrates are commonly found as strach in plant storage organs. Which of the following five properties of strach (A-E) make it useful as a storage material?
A. Easily translocated
B. Chemically non-reactive
C. Easily digested by animals
D. Osmotically inactive
E. Synthesised during photosynthesis

The useful properties are
(a) B and C (b) B and D
(c) A, C and E (d) A and E

19 Consider the following statements.
I. The portion of the spectrum between 500 nm is also referred to as Photosynthetically Active Radiation (PAR).
II. Magnesium, calcium and chloride ions play prominent roles in the photolysis of water.
III. In non-cyclic photophosphorylation, oxygen is not released (as there is no photolysis of water) and NADPH is also not produced.

Choose the correct option.
(a) I is true, but II and III are false
(b) I and II are false, but III is true
(c) II is true, but I and III are false
(d) I and II are true, but III is false

20 In the below schematic diagram, which is plastocyanin?



(a) C (b) D (c) A (d) B

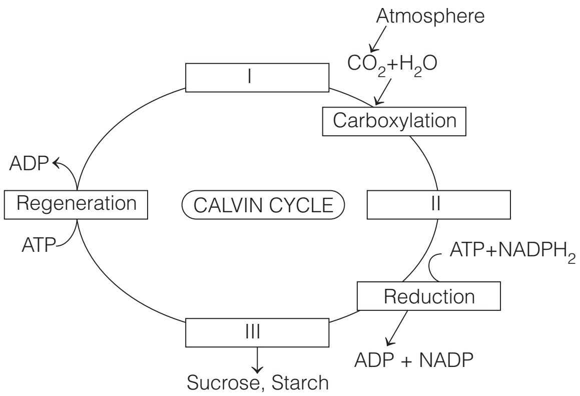
21 Match the following columns.

Column I (Scientist)	Column II (Contribution)
A. Peter Mitchell	1. Law of limiting factor
B. Blackman	2. Dark reaction of photosynthesis
C. Daniel Armon	3. Photosynthetic phosphorylation
D. Melvin Calvin	4. Chemiosmotic hypothesis

Codes

	A	B	C	D
(a)	4	1	3	2
(b)	1	4	2	3
(c)	2	1	3	4
(d)	4	3	2	1

22 Refer the given diagram which shows Calvin cycle, then choose the correct one from the given options



	I	II	III
(a)	RuBP	Triose phosphate	PGA
(b)	PGA	RuBP	Triose phosphate
(c)	PGA	Triose phosphate	RuBP
(d)	RuBP	PGA	Triose phosphate

Directions (Q. Nos. 23-25) *In each of the following questions a statement of Assertion is given followed by a corresponding statement of Reason just below it. Of the statements, mark the correct answer as*

(a) If both Assertion and Reason are true and Reason is the correct explanation of Assertion
(b) If both Assertion and Reason are true, but Reason is not the correct explanation of Assertion
(c) If Assertion is true, but Reason is false
(d) If both Assertion and Reason are false

23 **Assertion** The atmospheric concentration of CO_2 at which photosynthesis just compensates for respiration is referred to as CO_2 compensation point.
Reason The CO_2 compensation point is reached when the amount of CO_2 uptake is less than that generated through respiration because the level of CO_2 in the atmosphere is more than that required for achieving CO_2 compensation point.

24 **Assertion** Cyclic pathway of photosynthesis first appeared in some eubacterial species.
Reason Oxygen started accumulating in the atmosphere after the non-cyclic pathway of photosynthesis evolved.

25 **Assertion** Red light of visible spectrum contains high energy.
Reason Green light of visible spectrum contains low energy than red light.

ANSWERS

SESSION 1

1 (c)	**2** (d)	**3** (b)	**4** (c)	**5** (a)	**6** (a)	**7** (b)	**8** (d)	**9** (d)	**10** (d)
11 (a)	**12** (b)	**13** (c)	**14** (b)	**15** (d)	**16** (a)	**17** (b)	**18** (c)	**19** (c)	**20** (c)
21 (d)	**22** (c)	**23** (d)	**24** (b)	**25** (c)	**26** (b)	**27** (c)	**28** (d)	**29** (c)	**30** (a)
31 (a)	**32** (b)	**33** (b)	**34** (b)	**35** (a)	**36** (c)	**37** (c)	**38** (d)	**39** (c)	**40** (a)
41 (b)	**42** (c)	**43** (b)	**44** (a)	**45** (d)	**46** (c)	**47** (a)	**48** (a)	**49** (b)	**50** (a)
51 (c)	**52** (d)	**53** (b)	**54** (d)	**55** (c)	**56** (a)	**57** (d)	**58** (a)	**59** (b)	**60** (d)
61 (c)	**62** (a)	**63** (c)							

SESSION 2

1 (b)	**2** (b)	**3** (c)	**4** (a)	**5** (b)	**6** (c)	**7** (d)	**8** (a)	**9** (b)	**10** (a)
11 (b)	**12** (c)	**13** (a)	**14** (d)	**15** (a)	**16** (b)	**17** (b)	**18** (c)	**19** (c)	**20** (b)
21 (a)	**22** (d)	**23** (c)	**24** (b)	**25** (b)					