CHAPTER 15

PHOTOSYNTHESIS IN HIGHER PLANTS

Topics Discussed

1. Introduction

Nearly all of the members (with some exceptions) categorized under the kingdom Plantae are autotrophic in nature. Being autotrophic gives the plants the ability to synthesize their own food for their own nutrition and well being as well as providing a source of nutrition for heterotrophic organisms which are incapable of synthesizing their own food and hence are dependent on autotrophs. Plants fix gaseous carbon dioxide from the atmosphere and water transported from the roots in order to synthesize their food in the form of complex, organic substances, majorly sugars and starches while releasing free, gaseous oxygen which returns to the environment and is used by other organisms apart from the plant itself during respiration process. This process,which requires the presence of electromagnetic radiations (light) or solar energy (sun light) is termed as Photosynthesis. The light is captured by specialized organs in the leaves of plants termed as chloroplast which are abundant in light capturing, mostly green colored pigments termed as chlorophyll and the presence of these chlorophyll

pigments imparts green color to the leaves. Photosynthesis may appear like a single step process but is in fact a series or cascade of mechanisms that is constantly monitored, heavily regulated and under huge influence by a variety of factors.

Although higher plants and algae perform a majority of the photosynthetic activity, there are certain protists and bacteria such as cyanobacteria (blue green algae) which possess a light harvesting pigment termed as bacteriochlorophyll (ancient, archaic origin) and are also autotrophic in nature. However, their benefits to humans are very limited and hence they are not as well researched as plants.

Objectives

At the end of this, chapter you will be able to:

- Learn about photosynthesis process in higher plants. As mentioned before, photosynthesis is a cascade of reaction mechanisms and involve several participants and hence their contribution needs to be highlighted.
- Focus on the organs and pigments involved in photosynthesis, the different reactions involved in light-dependent reaction which involves cyclic and non-cyclic photophosphorylation along with Electron Transport System (ETS) and ATP synthesis.
- Cover in details the mechanisms of light-independent reactions or dark reactions such as C3 pathway, evolved C4 pathway of grasses and CAM pathway of succulent plants which shows how much plants have evolved and adapted their systems to efficiently synthesize their own food in accordance with their environment.
- Discuss the photorespiration process which show the dual nature, contrasting specific enzymes.
- Talk about Bacteriochlorophyll, which points towards an independent system of fixing carbon sources into organic molecules as well as the factors influencing the photosynthetic processes will be discussed.

2. Photosynthesis

'Photosynthesis is defined as the photo-biochemical/physicochemical mechanism, incorporating anabolic, reductive and endergonic processes carried out by green plants, in which complex, energy-rich organic compounds (carbohydrates such as sugars, starches) are synthesized from simple inorganic raw materials composed of water (H_2O) and carbon dioxide (CO_2) in presence of electromagnetic radiations (light or solar energy) and light capturing pigments (chlorophyll, carotenoids) with release of oxygen (O_2) as a byproduct.'

This mode of nutrition using photosynthesis process is termed as photoautotrophism.

The basic mode of photosynthesis occurs in the following steps:

- Absorption and retention of electromagnetic radiations (composed of photons and waves) in the form of light energy from the sun.
- Conversion of the dynamic, solar light energy into stable, chemical potential (energy) which is stored.

- Hence, the overall reaction of photosynthesis is shown as

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

Did You Know

- Nearly 90% of the total photosynthesis seen on Earth is carried out by marine plants composed of phytoplankton and algae while only 10% is carried out by terrestrial plants.
- Approximate annual fixation of carbon in the form of CO_2 through photosynthesis is around 258 billion tons.
- In photosynthesis, light energy (dynamic) is converted into chemical energy (stable and storage). Only about 0.2% of the total light energy falling on the earth is utilized by photosynthetic organisms.
- First organism capable of photosynthesis were bacteria but first true and oxygenic photosynthesis was discovered in cyanobacteria/blue green algae (BGA).

2.1 Historical Landmarks in Studies of Photosynthesis

A record of the early studies and experiments conducted which served as landmarks in the field of photosynthesis are listed below

- The first scientist to establish the fact that gaseous constituents of air and components of light, both contributes towards the building up of the plant body and photosynthetic nourishment occurring in plants plant was Stephan Hales (1927).
- He is also considered to have discovered the process of photosynthesis and is called as **'Father of Plant Physiology'.**
- Joseph Priestley (1770) demonstrated that purification of the respired air released by animals was carried out by plants. In a series of experiments involving bell jar, candle, mint (pudina) plant and rat the essential role of air in the growth, development and survival of green plants was demonstrated.
- Priestley noted that candle burning on its own in a closed space such as a bell jar, gets extinguished very quickly. Burning of the candle results in the generation of impure air which was labeled as phlogiston. When a live mouse was placed along with the candle in the closed bell jar, it resulted in the death of the mouse due to suffocation. However, on placing a live mint plant in the closed bell jar containing the burning candle and live mouse both resulted in both the plant and mouse surviving while the burning of candle continues. The final conclusion achieved was that the candle which requires air continued burning and/or the animal that breathes air remained alive due to the presence of plants. The hypothesis proposed by Priestley was that the restoration of the phlogiston to its pure form, which was termed as dephlogiston was achieved by plants. This pure air or dephlogiston was whatever breathing

animals and burning candles remove. Oxygen as an essential gas for survival was also established by Priestley (1774).

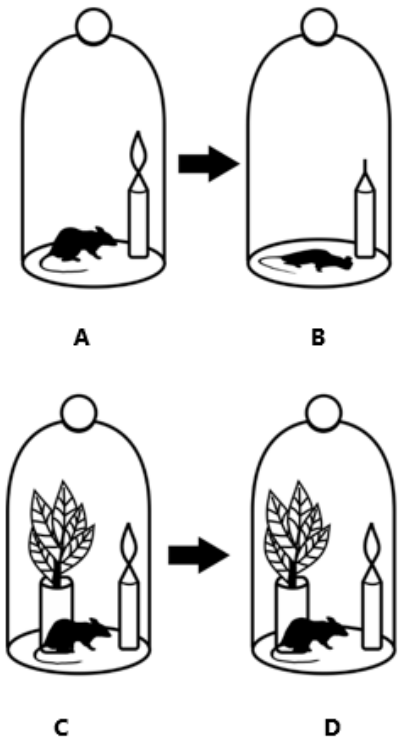

Figure 15.1: Presley's experiment

A and **B** Animal does not survive as candle used up the oxygen.

C and **D** - The plant replenishes oxygen by using up the carbon-dioxide and hence the animal survives.

- **Jan Ingenhousz** stated that green leaves give out dephlogisticated air (air rich in oxygen) in presence of sunlight while in the absence of sunlight (in the dark) they give out phlogisticated air (air rich in CO_2) and make the air 'impure'.
- **Jean Senebier** discovered that green plants utilize carbon dioxide. This is regarded as a very important discovery in the field of photosynthesis.
- **N.T. de Saussure** showed that during photosynthesis, the volume of carbon dioxide consumed by plants is equal to the volume of oxygen liberated by them. Saussure also proved that water is necessary for photosynthesis.
- **Pelletier and Caventou** denoted the green colored substance in the leaves as 'chlorophyll'.
- **F.F. Blackman** noted that photosynthesis is carried out in two steps: a photochemical reaction which requires the presence of light and a reaction for which light is not necessary (light and dark reactions). Blackman also out forth the law of limiting factor.

- **Warburg** performed the Flashing experiment 1919.
- **Emerson and Arnold** showed that the light reaction of photosynthesis has two distinct photochemical processes.
- **Robert Hill** using *Stellaria* showed that isolated chloroplasts in the presence of sunlight, water and a suitable hydrogen acceptor, release oxygen, even if carbon dioxide is absent. This experiment is considered to be equivalent to the light reaction. Hill used certain chemicals termed as 'Hill's reagents'. They are redox dyes which change colours when reduced. The common electron acceptors are ferricyanide, benzoquinone and dichlorophenol indophenol (DCPIP), while $NADP^+$ is a natural H^+ acceptor in photosynthesis.
- **Van Niel,** carried out experiments using green and purple sulphur bacteria. He showed that hydrogen released from suitable oxidisable compounds reduces CO_2 to carbohydrates also put forth that water is the source of oxygen in photosynthesis.

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

- **Mayer** stated that green plants convert the solar energy into chemical (potential) energy in the form of organic substances.
- **Ruben, Hassid and Kamen** carried out experiments using radioactive oxygen (O^{18}) and proved that that the source of oxygen in photosynthesis is water.

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

- **Julius von Sachs** (1854) discovered that the green parts in plants is where glucose is synthesized and that glucose is usually stored as starch.
- **T.W Engelmann** worked using on *Cladophora and Spirogyra.* He noted that when light is split using a prism and used to illuminate the algae, the organisms aggregate in the blue and red regions.
- **Melvin Calvin** along with his co-workers used radioactive carbon to study the various reactions involved in conversion of CO_2 to carbohydrates. They elucidated a bio-chemical pathway called the C_3 or the Calvin's cycle. Calvin won a Noble Prize in 1961.
- **MD Hatch and C.R Slack** elucidated another bio-chemical pathway for CO_2 fixation which is carried out in tropical plants. The first compound in the pathway is 4 carbon compound and hence the pathway is called the for C_4 cycle.
- **Huber et. al.** worked on understanding the 3-D stricture of the reaction center of the bacteria *Rhodopseudomonas viridis*. They also won a Nobel Prize.

Did You Know

- In the presence of monochromatic light longer than 680 nm wavelength, the quantum yield of photosynthesis suddenly drops down, this phenomenon is called as **red drop.**
- When non-monochromatic light of wavelengths shorter and greater than 680 nm (combined light) is provided the, photosynthetic, activity increases, this is called as **Emerson effect or enhancement effect.**

3. Pigments Participating in Photosynthesis

There are three main types of photosynthetic pigments–Chlorophylls, Carotenoids and Phycobilins.

3.1 Chlorophylls

- Chlorophyll – Chloros in Greek means green while phyllon means leaf.
- They are the photosynthetic pigments found in higher plants and many other photosynthetic organisms.
- They are the main pigments concerned with harvesting solar energy.
- They are specialized lipid molecules embedded in thylakoid membrane of the chloroplasts.
- Arnoff and Allen (1966) recognized 9 types of chlorophylls.

  Some of them are (1) Chlorophyll-a; (2) Chlorophyll-b, (3) Chlorophyll-c etc.
- Chlorophyll-a and chlorophyll-b are the two main types of chlorophylls found in plants.
- Generally light energy absorbed by other photosynthetic pigment is transferred to chlorophyll-a.

- **Chlorophyll-a:**
  - Empirical formula of chlorophyll-a is $\mathbf{C_{55}H_{72}O_5N_4Mg}$
  - Chlorophyll a molecule has a porphyrin (a tetrapyrrole closed ring derivative) head and a phytol ($C_{20}H_{39}OH$) tail.
  - A vinyl group is present at the second carbon position in the tetrapyrrole ring.
  - A methyl group is present at the third carbon position of the tetrapyrrole ring.
  - An Mg atom in nonionic form is held within the head with two covalent and two coordinate bonds.
  - Chlorophyll-a absorbs violet blue and red lights with absorption maxima at 430 nm and 662 nm.
  - Except for bacteria, it is found in all photosynthetic organisms.

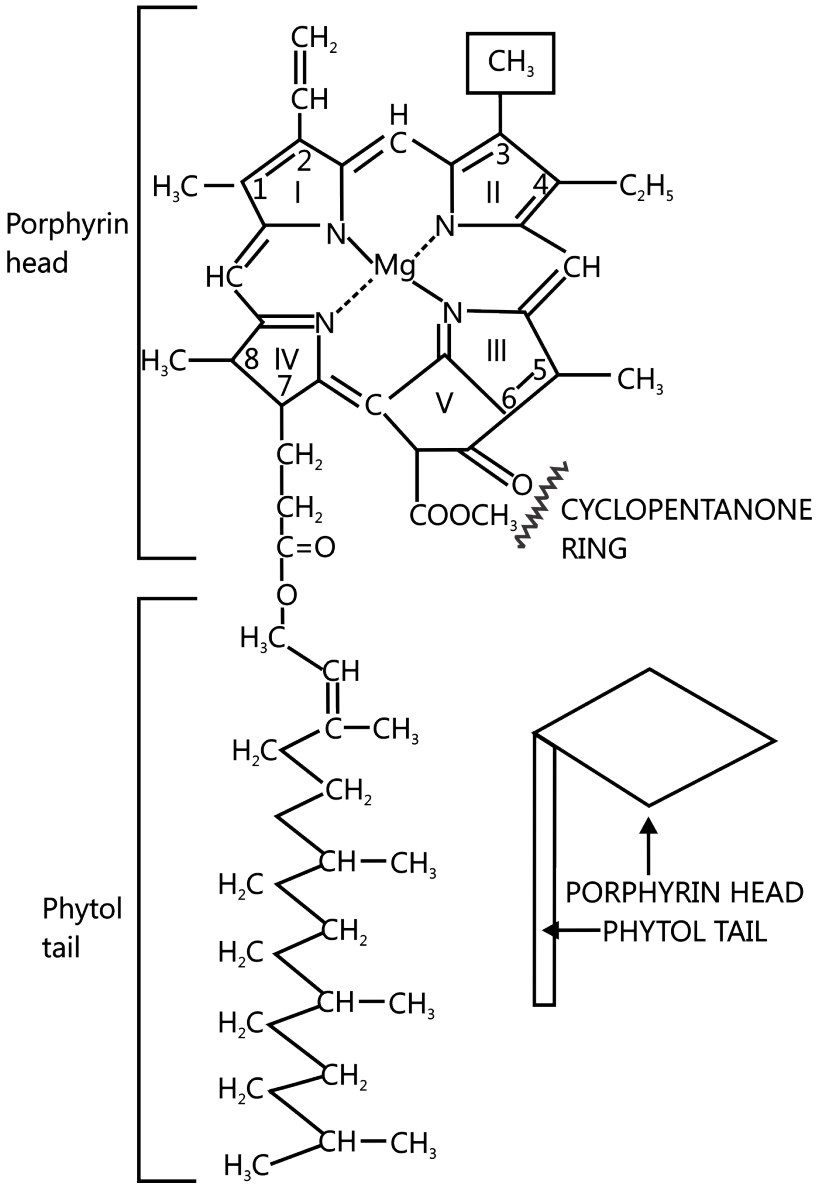

Figure 15.2: Chlorophyll-a

- **Chlorophyll-b:**
  - The empirical formula of chlorophyll-b is $\mathbf{C_{55}H_{70}O_6N_4Mg}$.
  - It has a formyl (CHO) group at the third carbon position of the tetrapyrrole ring. Otherwise, it is similar to chlorophyll-a.
  - It absorbs blue and orange wavelengths with the absorption maxima at 430 nm and 644 nm.
- **Chlorophyll-c:**
  - Chlorophyll-c lacks phytol esterification.
  - It is found in brown algae, diatoms and dinoflagellates.
- **Chlorophyll-d:**
  - It absorbs in far red wavelength of light.
  - It is found in brown algae and other organisms that thrive in moderately deep zones of water bodies.
- **Bacteriochlorophyll:**
  - The molecular formula is $\mathbf{C_{55}H_{74}O_6N_4Mg}$.
  - It is very similar to chlorophyll-a except for the presence of acetyl group instead of vinyl at the second carbon position of the tetrapyrrole ring.
- **Chlorobium chlorophyll:**
  - Also known as bacterioviridin.
  - It has hydroxyl-methyl group (CH_3CHOH) at the second carbon position in the tetrapyrrole nucleus.
  - Its general formula is $\mathbf{C_{51}H_{67}O_{64}N_4}$ Mg in (Chlorobium) photosynthetic bacteria.

3.2 Carotenoids

- Carotenoids are yellow to orange lipid compounds
- They occur in almost all higher plants.
- Carotenoids are of two types- carotenes and xanthophylls.
- **Carotenes**
  - Carotenes are reduced molecules. Their general form is $C_{40}H_{56}$.
  - Carotenes are of several types like **α** and **β**.
  - The most widespread and important carotene associated with chlorophyll inphotosynthetic organisms is β-carotene. It is orange-yellow in colour.
  - A molecule of carotene is broken down into two molecules of vitamin A in vertebrates during digestion.
  - A carotene called lycopene is responsible for the red colour of tomatoes.

- **Xanthophylls**
  - Xanthophylls also contain oxygen along with carbon and hydrogen.
  - They are yellow colored pigments.
  - They are found in papayas peaches and prunes.
  - They are present in the human eye and help to protect it against ionizing effect of some radiations.
  - Examples include Lutein ($C_{40}H_{56}O_2$), cryptoxanthin ($C_{40}H_{56}O$), etc.

3.3 Phycobilins

- They are also called biliproteins.
- They are accessory pigments found in red algae and cyanobacteria.
- They have open chain tetrapyrrole structure.
- They are soluble on hot water.
- Phycoerythrins and Phycocyanins are two types of Phycobilins.
- Generally it is seen that both types occur together. However the proportion may vary according to the species and environment.

3.4 Quantasome

- They are considered as the units of photosynthesis.
- They were first identified by **Roderic B. Park** in 1962.
- They consist of lipids and proteins and are found in the thylakoid membrane of chloroplasts.
- They contain various photosynthetic pigments and redox carriers.
- They occur in 2 sizes- the smaller quantasome is thought to represent the site of photosystem I and the larger one to represent the site of photosystem II.

3.5 Absorption and Action Spectra

- Absorption spectrum is represented as a graph obtained by plotting Absorption vs Wavelength for a particular pigment.
- Different photosynthetic pigments absorb only certain wave lengths.
- Action spectrum is a graph showing the effectiveness of different wavelengths of light in stimulating the process under investigation.
- It was first studied by Engelmann on *Cladophora.*
- Effectiveness is measured by analyzing quantum yield or amount of action which can be denoted through CO_2 reduction, O_2 release etc.

3.6 Photosystems

- Photosystems are functional and structural units consisting of protein complexes involved in photosynthesis.
- They are located in the thylakoid membranes of plants and algae or in the cytoplasmic membrane of photosynthetic bacteria.
- There are two kinds of photosystems: Photosystem I and Photosystem II.
- Both photosystems I and II are required for oxygenic photosynthesis.
- The photosystem I was named "I" since it was discovered before photosystem II, but this does not represent the order of the electron flow.
- PSUs (Photosynthetic units) are present on the thylakoid membranes.
- PSUs are made up of 250 - 400 molecules of various pigments.
- The PS II is located in the appressed region of granal thylakoids.
- PS I is found in the non appressed region of grana and stoma thylakoids.

Knowledge Builder

- The porphyrin head of the chlorophyll is hydrophilic and phytol tail is lipophilic (hydrophobic).
- Chlorophylls are soluble only in organic solvents like ethers etc.
- In paper chromatography

Chlorophyll-a	-	Bright or blue–green.
Chlorophyll-b	-	Yellow green/grass green.
Xanthophyll	-	Yellow
Carotenoids	-	Yellow to yellow–orange

- Chlorophyll synthesis-

$$\text{Succinyl CoA + Glycine -> Protochlorophyllide} \xrightarrow[2H]{\text{Light}} \text{Chlorophyll}$$

Try It Yourself

1. Raw materials for the synthesis of chlorophyll are _____ and _____.
2. Chlorophyll has _____ atom in co-ordination with the head. (Mg/Hg).
3. Xanthophylls are phycobilins. (True/False)
4. A vinyl group is present at the second carbon position in the tetrapyrrole ring. (True/False)

4. Mechanism of Photosynthesis

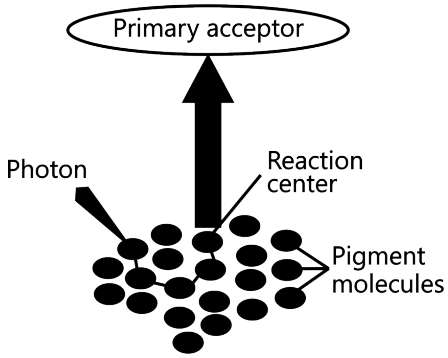

Figure 15.3: The first step of photophosphorylation

4.1 Light Reaction/Hill Reaction

Alternate names – Light reaction/Hill reaction/Photochemical reaction/Generation of assimilatory powers ($NADPH_2$ + ATPs)/Photophase.

4.1.1 Cyclic Photophosphorylation

- In cyclic photophosphorylation, only PS-I works.
- PS I consists of Chlorophyll –a 670, Chlorophyll-a 683, Chlorophyll-a 695, carotenoids, some molecules of Chlorophyll-b and reaction centre-Chlorophyll-a 700 or P-700.
- This form of photophosphorylation occurs on the thylakoid membrane.
- The electron begins PS I, passes from the primary acceptor to ferredoxin reducing substance (FRS), then to ferredoxin, then to cytochrome b6f and then to plastocyanin before returning to PS I.
- This process produces a proton-motive force, pumping H^+ ions across the membrane thereby generating a concentration gradient that can be used to power ATP synthase during chemiosmosis.
- Cyclic photophosphorylation neither produces O_2 nor NADPH.

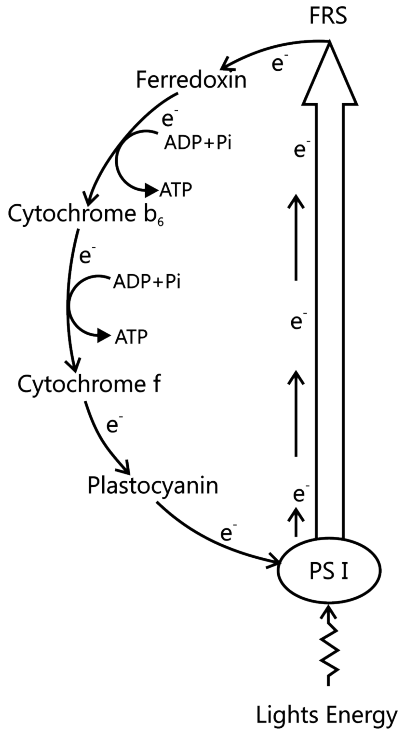

Figure 15.4: Cyclic photophosphorylation

- Unlike non-cyclic photophosphorylation, $NADP^+$ does not accept the electrons, they are instead sent back to cytochrome b6f complex.
- This process is mostly seen in bacteria and favored in anaerobic conditions.

Process overview-

Light- PS I → FRS → Ferredoxin → Cytochrome b6f → Plastocyanin → PS I

4.1.2 Non-Cyclic Photophosphorylation

- It is also termed as Z-scheme.
- Both PS-I and PS-II involved in non-cyclic photophosphorylation.
- PS-II (P-680) consists of Chlorophyll-a 660, Chlorophyll-a 673, Chlorophyll-a 690, Chlorophyll-b, or Chlorophyll-c or Chlorophyll-d, carotenoids and phycobilins. Chlorophyll-a 680 is the reaction centre.
- It occurs in stroma lamellae.
- The electrons do not go back to the reaction centre but rather are accepted by $NADP^+$.
- Photolysis of water uses up the electrons and leads to the formation of ATP and $NADPH_2$.
- The steps in the process begin with the PS II. Electrons are passed to Plastoquinone reducing substance (PQRS). PQRS passes them to plastoquinone which passes them to the cytochrome system. The cytochrome system passes them to plastocyanin which in in turn passes them to PS I.
- The steps afterwards include FRS, ferredoxin and NADP reductase.

Photolysis-

- Photolysis is a chemical reaction in which a compound is broken down by photons.
- It is an important reaction in photosynthesis.

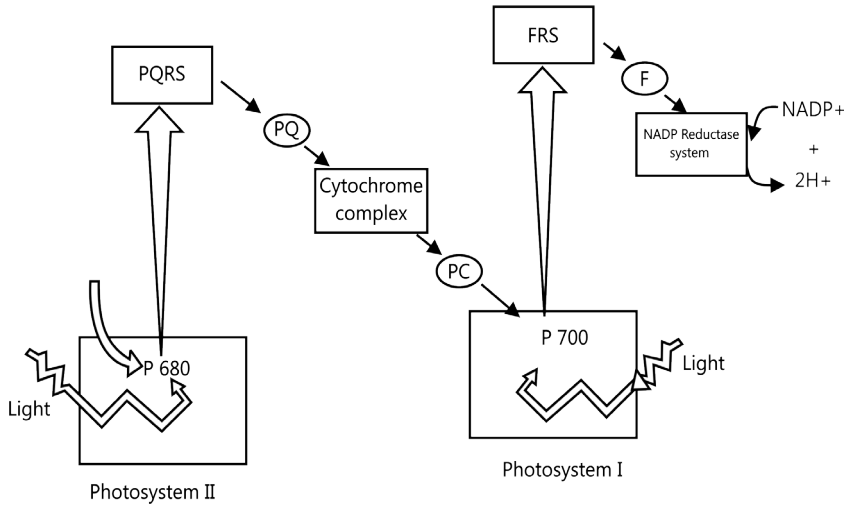

Figure 15.5: Non cyclic photophosphorylation

- The photolysis reaction in photosynthesis is similar to-

  H_2A + 2 photons (light) $\rightarrow$ 2 e^- + 2 H^+ + A

- In many cases the A is **oxygen**. In purple sulfur bacteria, the A is **sulfur**. Thus, in place of water these bacteria use hydrogen sulfide.
- Photolysis of water-

  $2H_2O \rightarrow 4H^+ + 4e^- + O_2$
  $NADP^+ + 2H^+ + 2e^- \rightarrow NADPH + H^+$

Process overview-

(Light-)PS II (Photolysis of water) $\rightarrow$ PQRS $\rightarrow$ PQ $\rightarrow$ Cytochrome complex $\rightarrow$ Plastocyanin $\rightarrow$ (Light-) PS I $\rightarrow$ FRS $\rightarrow$ Ferredoxin $\rightarrow$ NADP Reductase system

Chemiosmotic theory:

- It was put forth by Peter Mitchell to explain ATP formation.
- During the electron transport chain of photosynthesis the H^+ concentration gradually increases in thylakoid lumen.
- There are three causes of difference in H^+ ion concentration –
  - Photolysis of H_2O produces H^+
  - PQ shifting of H^+ ion from stroma to lumen.
  - NADP reductase mediated utilization of H^+ form stroma.
- A proton gradient and electrical potential is generated across the thylakoid membrane due to the differential H^+ ion concentration.
- The gradient and the electrical potential are collectively called proton motive force (PMF).
- The passage of H^+ ions leads to activation of ATP synthase which synthesizes ATP from ADP and Inorganic phosphate (Pi).

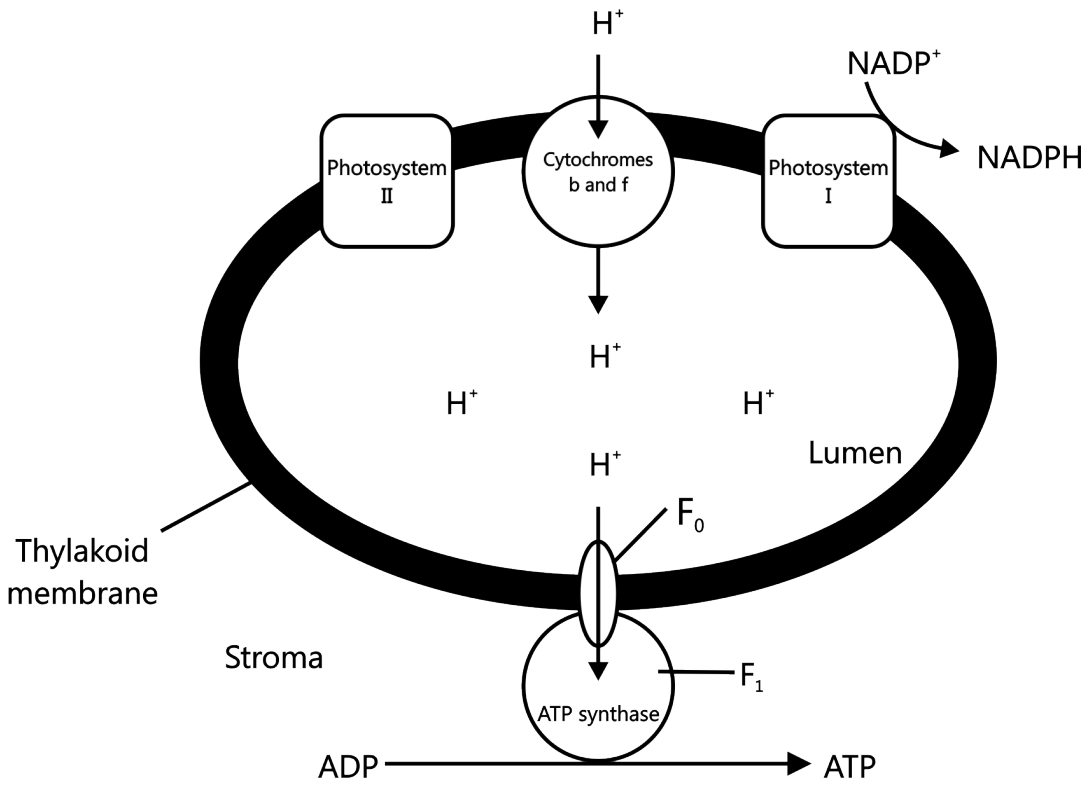

Figure 15.6: Chemiosmotic hypothesis

Table 15.1: Cyclic and Non-cyclic photophosphorylation

Cyclic photophosphorylation	Non-cyclic photophosphorylation
Only PS-I involved in cyclic process.	Both PS- II and PS-I works in non-cyclic process.
The e^- expelled from chl-700 is cycled back.	The e^- expelled from reaction centre is not cycled back. Its loss is compensated by e^- from H_2O.
Photolysis of water and evolution of O_2 does not take place.	Photolysis of water and evolution of O_2 takes place.
$NADP^+$ is not reduced.	$NADP^+$ is reduced to NADPH.
680 nm light.	Activated by light of wavelength 680 nm or sometimes less.

KNOWLEDGE BUILDER

- Quantum requirement –

  The number of light Quanta or photons required 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 photosynthesis is called as Quantum yield. Emerson calculated that the quantum requirement is 8. Hence, the quantum yield is 0.125 or 12.5%

4.2 Dark Reaction/Calvin Cycle

4.2.1 C3 Cycle/Pathway

Alternative names – Dark Reaction/Blackman Reaction/Calvin cycle/C_3-Cycle/Biochemical phase/ Carbon assimilation/photosynthetic carbon reduction cycle (PCR-cycle)/Reductive pentose phosphates pathway-

- C_3 cycle is comes under dark reactions, as no direct light is required for the process to be carried out.
- Calvin presented these reactions in a cyclic manner and it is thus called as Calvin cycle. A three carbon compound called PGA (Phosphoglyceric acid) is the first stable compound produced during Calvin cycle. Hence, the cycle is also called as C_3- cycle.
- Calvin carried out his experiment using an algae system, chromatography and radioisotopy with radioactive carbon- C^{14}.
- Rubisco (Ribulose bis-phosphate carboxylase-oxygenase) is an important enzyme of the Calvin cycle. It is present in stroma. CO_2-acceptor in Calvin cycle is RuBP.
- In order to form one glucose molecule, 6 turns of Calvin cycle are required.
- 12 ATP molecules are used up to form a molecule of glucose.

DID YOU KNOW

- The 1st compound formed in the Calvin cycle is unstable, it is 6 Carbon keto acid.
- Rubisco is most abundant enzyme found in living systems.

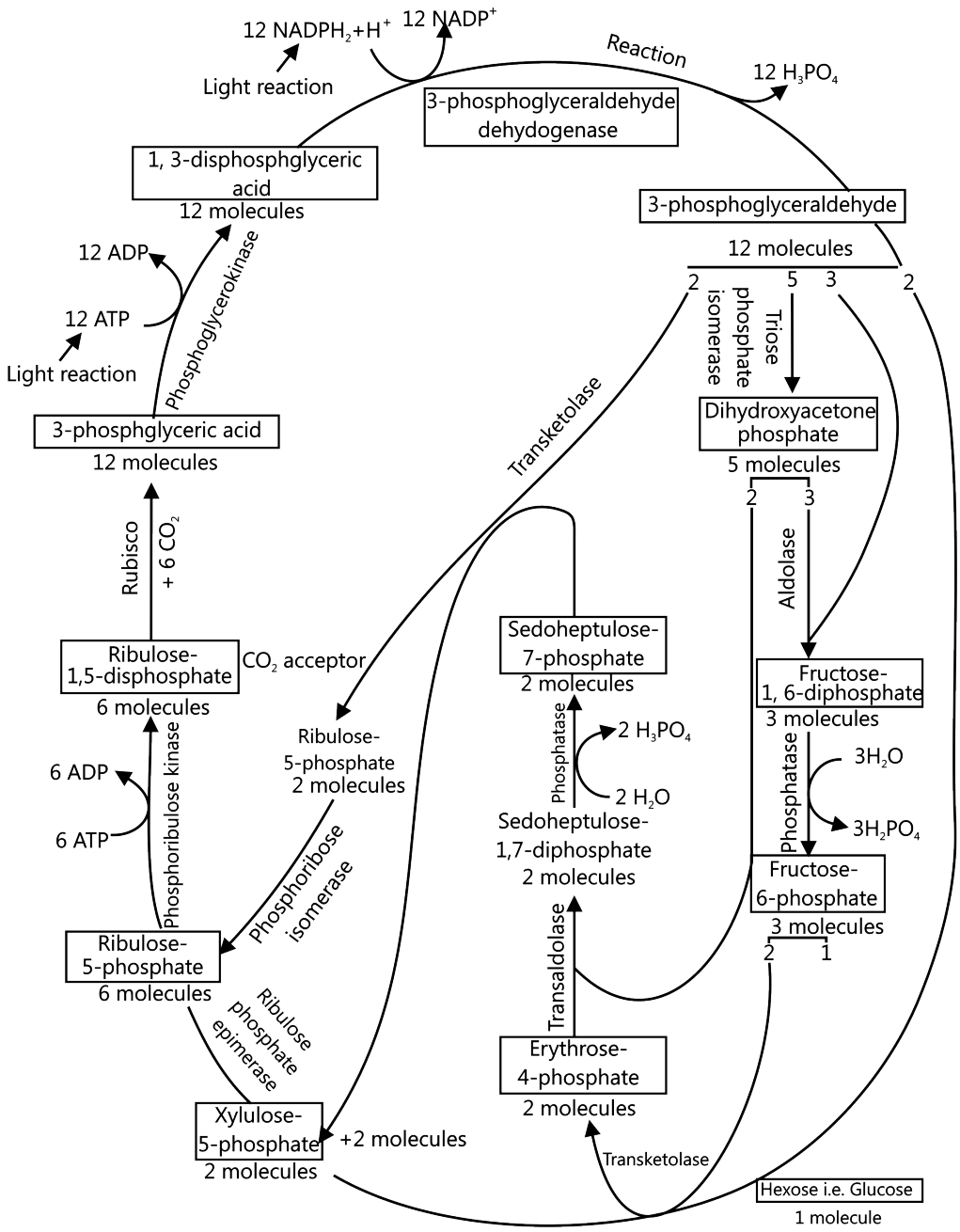

Figure 15.7: Schematic representation of Calvin Cycle

Biochemical reaction of Calvin cycle are as follows –

- **Carboxylation**

  The enzyme Rubiscocatalyzes the carboxylation of ribulose-1,5-bisphosphate (RuBP) a 5-carbon compound, by carbon dioxide (a total of 6 carbons) in a two-step reaction.

6 molecules of RuBp (RuDp) + 6 molecules of CO_2 (HCO_3^-) $\xrightarrow[\text{(Carboxydismutase)}]{\text{Rubisco}}$ 6C

unstable compound $\rightarrow$ 12 molecules of 3 – PGA (3C)

- **Glycolytic reversal**

  The enzyme phosphoglycerate kinase catalyzes the phosphorylation of 3-PGA by ATP. 1,3-Bisphosphoglycerate (1,3Bi PGA, glycerate-1,3-bisphosphate) and ADP are the products.

$$\underset{(3C)}{12 \text{ molecules of } 3-\text{PGA}} + 12\,\text{ATP} \xrightarrow{\text{Phosphoglycerate kinase}} 12 \text{ molecules of } 1,3-\text{Bi PGA}$$

- **Formation of G3P or PGAL**

  The enzyme glyceraldehyde-3-phosphate dehydrogenase catalyzes the reduction of 1,3 BPGA by NADPH. Glyceraldehyde-3-phosphate or G3P is formed.

- **Isomerization of PGAL to DHAP (Dihydroxy acetone phosphate)**

  Triose phosphate isomerase converts all of the G3P reversibly into dihydroxyacetone phosphate (DHAP), also a 3-carbon molecule.

- **Formation of a molecule of Fructose 6 Phosphate**

  Aldolase and fructose-1,6-bisphosphatase convert a G3P and a DHAP into fructose-6-phosphate.

$$\underset{9C\ (3C \times 3)}{3 \text{ molecules of PGAL}} + \underset{(9C)\ (3C \times 3)}{3 \text{ molecules of DHAP}} \xrightarrow{\text{Aldolase}} \underset{(18C)\ (6C \times 3)}{3 \text{ molecules of Fructose}-1,6-\text{Biphosphate}}$$

- **Formation of Xylulose phosphate**

  F6P has two carbons removed by transketolase, giving erythrose-4-phosphate. The two carbons on transketolase are added to a G3P, giving the ketose xylulose-5-phosphate (Xu5P).

$$\underset{(12C)}{2 \text{ molecules of Fructose}-6-\text{P}} + \underset{(6C)}{2\text{PGAL}} \xrightarrow{\text{Transketolase}} \underset{(8C)}{2 \text{ molecules of Erythrose}-\text{P}} + \underset{(10C)}{2 \text{ molecules of Xylulose}-\text{P}}$$

- **Formation of Sedoheptulose Bisphosphate**

  E4P and a DHAP (formed from one of the G3P from the second CO_2 fixation) are converted into sedoheptulose-1,7-bisphosphate (7C) by aldolase enzyme.

$$\underset{(8C)}{2 \text{ molecules of Erythrose}-4-\text{P}} + \underset{(6C)}{2 \text{ molecules of DHAP}} \xrightarrow{\text{Aldolase}} \underset{(14C)}{2 \text{ molecules of Sedoheptulose}-1,7-\text{BiP}}$$

- **Sedoheptulose 1,7- BiP to Sedoheptulose7P**

  Sedoheptulose-1,7-bisphosphatasecleaves sedoheptulose-1,7-bisphosphate into sedoheptulose-7-phosphate, releasing an inorganic phosphate ion into solution.

- Formation of Ribulose phosphate

  The ketose Sedoheptulose 7P has two carbons removed by transketolase, giving ribose-5-phosphate (R5P),

$$\underset{(14C)}{\text{2 molecules of Sedoheptulose}-P} + \underset{(6C)}{\text{2 PGAL}} \xrightarrow{\text{Trans Ketolase}} \underset{(10C)}{\text{2 molecules of Xylulose}-P} + \underset{(10C)}{\text{2 molecules of Ribose}-P}$$

- **Xylulose Phosphate epimerization**

  Xylulose phosphate epimerizes to Ribulose phosphate catalyzed by phosphopentose epimerase.

$$\underset{(10C)}{\text{2 molecules of Xylulose}-P} + \underset{(10C)}{\text{2 molecules of Xylulose}-P} \xrightarrow{\text{Epimerase}} \underset{(20C)}{\text{4 molecules of Ribulose}-5-P}$$

- **Isomerization of Ribose 5P to Ribulose 5P**

  R5P is converted into ribulose-5-phosphate (Ru5P, RuP) by phosphopentose isomerase.

$$\underset{(10C)}{\text{2 molecules of Ribose}-5P} \xrightarrow{\text{Isomerase}} \underset{(10C)}{\text{2 molecules of Ribulose}-5P}$$

- **Phosphorylation of Ru5P**

  Phoribulokinase phosphorylates RuP into RuBP, ribulose-1,5-bisphosphate, completing the Calvin cycle. This requires the input of one ATP.

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

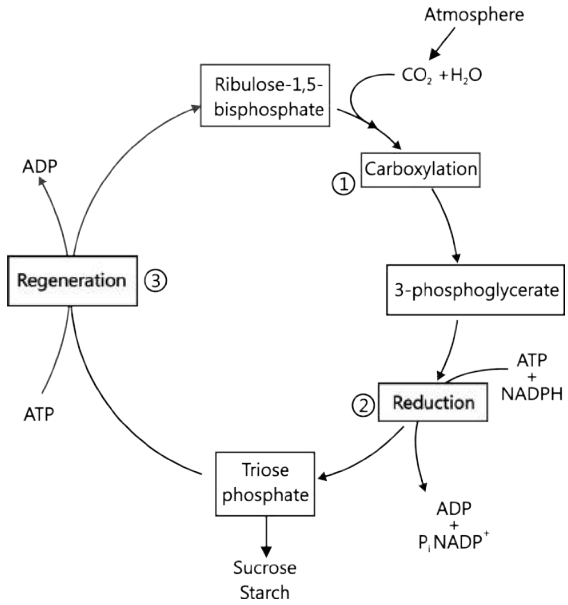

Figure 15.8: Stages of Calvin cycle- carboxylation, reduction and regeneration

KNOWLEDGE BUILDER

- Rubisco enzyme has one large and one small subunit.
- Magnesium ion is required for the proper functionality of Rubisco.
- Interestingly, some scientists are hoping to genetically engineer the expression of Rubisco with an aim to sequester more carbon-dioxide and thereby tackle global warming.

4.2.2 C4 Cycle/Pathway

Alternative names – CO_2 concentrating mechanism/Co-operative photosynthesis/Dicarboxylic acid cycle (DCA cycle)/C_4 cycle/Hatch and Slack pathway

- Kortschak and Hatch first observed that 4C, OAA (Oxaloacetic acid) is formed in sugarcane leaves during dark reaction.
- A pathway for dark reactions in sugarcane and maize leaves was proposed by **Hatch and Slack.**
- C_4-cycle occurs in 19 families of angiosperms, but mostlyin monocots, belonging to **families Gramineae (True grasses) e.g. sugarcane, Maize, sorghum etc. and Cyperaceae (sedges) e.g. water chestnut.**
- **Kranz Anatomy** is seen in leaves of C_4 plants.
- Green bundle sheath cells (BS cells) present around the vascular bundles.
- Two types of chloroplasts are present in the leaf cells. In mesophyll cells, chloroplasts are small and with grana while chloroplasts of B.S. cells are larger and without grana.
- PEPCase (Phosphoenol pyruvate carboxylase) enzyme is present in mesophyll cells while Rubisco is present in BS cells.
- In the C_4-plants, C_3-cycle occurs in bundle sheath cells, while C_4-cycle occurs in mesophyll cells.
- Photosynthetically C_4 plants are more efficient as there is no photorespiration. BS cells do not release O_2 and mesophyll cells pump more CO_2 for C_3 cycle.
- C_4-plants are found in tropical habitats. They have adapted themselves to the environment with high temperature, low water availability and intense light.
- Primary CO_2 acceptor in C_4 is PEP (phosphoenol pyruvate). It is a 3 carbon compound.
- First carboxylation in C_4-cycle is catalyzed by PEPCase in thecytoplasm of mesophyll cells.
- The second carboxylation or final CO_2 fixation occurs in BS cells by through the C_3 cycle.
- For the production of 1 hexose (Glucose) molecule in C_4-plants, 30 ATP molecules are used up.
- The enzyme pyruvate phosphate dikinase (PPDK) converts pyruvate to PEP by converting an ATP to AMP. This regeneration of PEP helps C_4 plants increase the efficiency of CO_2 fixation.

Special features of C4 plants –

- C_4 plants are more efficient than C_3 plants with respect to carbon fixation.
- The productivity in C_4 plants, does not increase when CO_2 concentration is increased.
- The reasons for this are-
    - Mesophyll cells pump more CO_2 for Calvin cycle
    - Thus concentration of CO_2 is high around the site of Rubisco in C_4 plants.

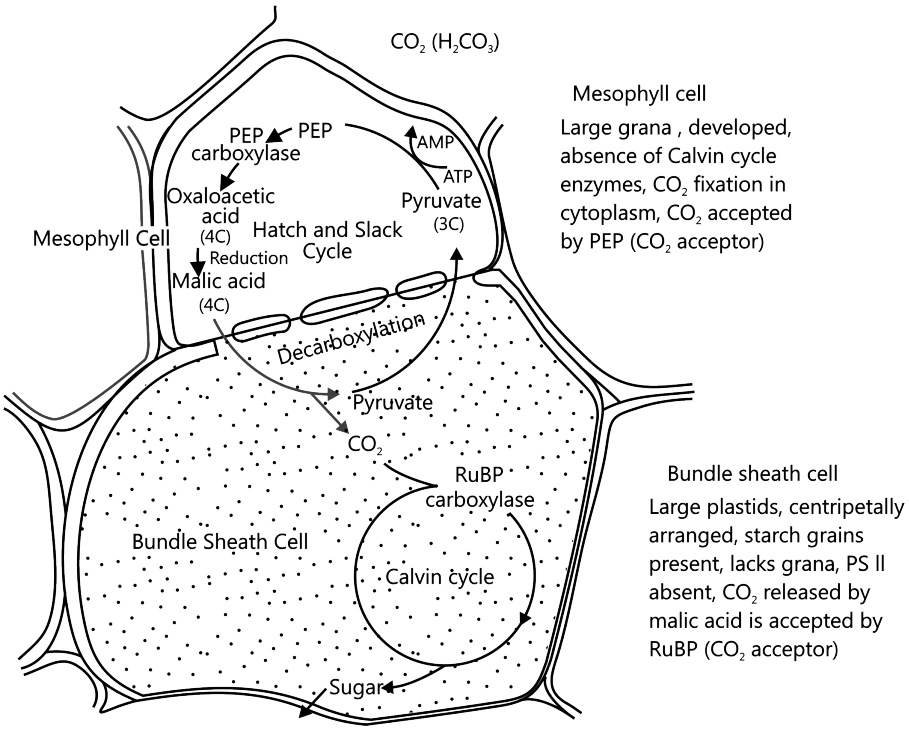

Figure 15.9: Schematic representation of C_4 pathway

Steps in C_4 pathway

- The pathway begins with the conversion of pyruvate to phosphoenolpyruvate (PEP), by the enzyme pyruvate orthophosphate dikinase.
- The next step is the fixation of CO_2 into oxaloacetate (OAA) by the enzyme PEP carboxylase. Both of these steps occur in the mesophyll cells.
- OAA converted to malate, a simple organic compound, which is transported to the bundle-sheath cells.
- Malate is decarboxylated to produce CO_2 and pyruvate.
- The CO_2 now enters the Calvin cycle and the pyruvate is transported back to the mesophyll cell.

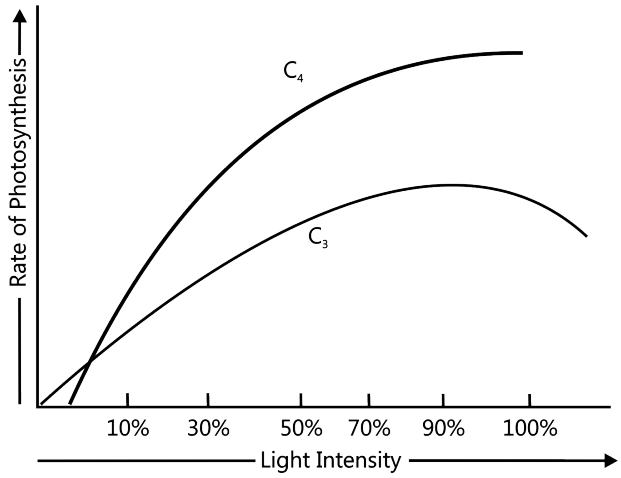

Figure 15.10: C_3 – C_4 dependence on light intensity

KNOWLEDGE BUILDER

- Calvin's experiment that led to the elucidation of the Calvin's cycle is also called as the 'Lollipop experiment' based on the shape of the apparatus used.
- Scientists are attempting to produce C_4 rice. This variety will produce 50% more grain and use less water. This can drastically improve the food security situation on the world.

4.2.3 CAM Pathway

Alternative names – CAM-Plants/Crassulacean acid metabolism/Dark CO_2 fixation/Dark acidification

- It is observed in succulent xerophyte plants **e.g. *Kalanchoe, Bryophyllum, Sedum, Kleinia* etc.**
- Primary acceptor of CO_2 is PEP (Phosphoenol pyruvate)
- Oxaloacetic acid is the first product of the carboxylation reaction.
- In CAM plants stomata are of scotoactive type (they open at night). Organic acids are produced during night and they are broken down during the day. Final CO_2 fixation (C_3 cycle) occurs in day time.
- PEPCase induces carboxylation reaction in night.
- PEP carboxylase and Rubisco present in mesophyll cells.
- Kranz-anatomy is not seen.
- Synthesis of 1 molecule of glucose requires 30 ATPs
- Thus, CAM plants leave the stomata closed during the day. This highly reduces the water loss.

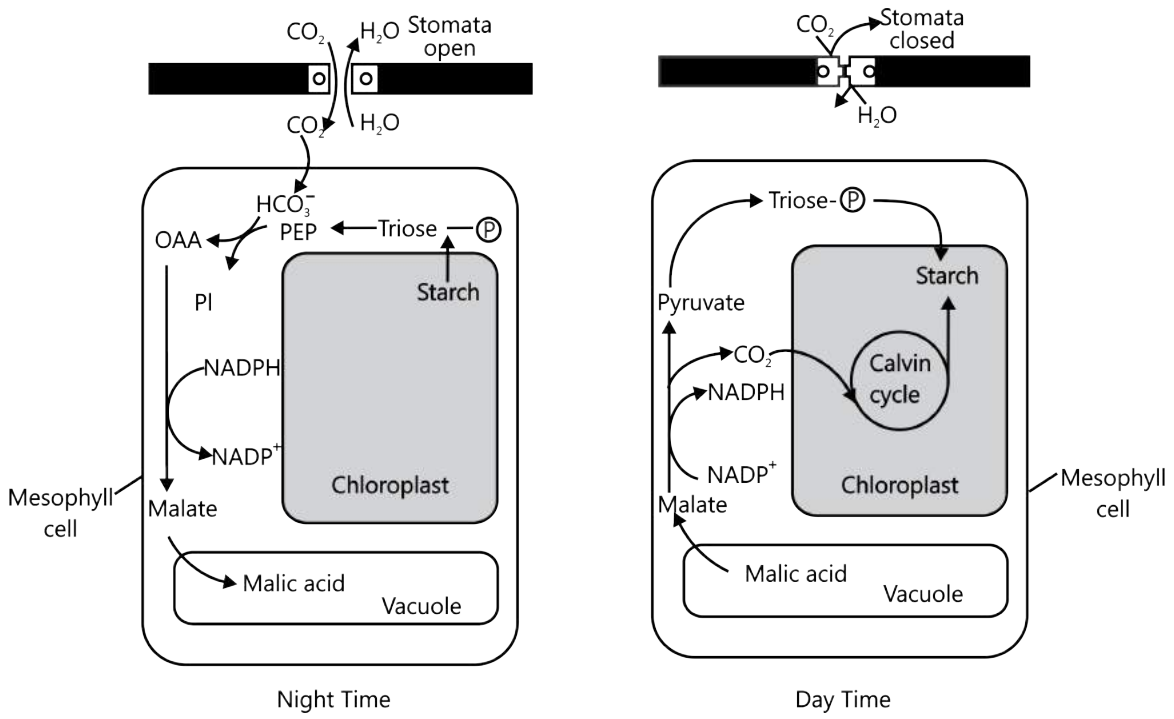

Figure 15.11: CAM pathway

5. Photorespiration

Photosynthetic carbon oxidation cycle/C_2Cycle/ Photorespiration/Glycolate-Metabolism

- Rubisco has some affinity for O_2. Hence, sometimes oxygen is added to RuBP instead of CO_2.
- Instead of PGA, phosphoglycolate (PA) is produced.
- PA is recycled to produce PGA via the photorespiratory pathway.
- Photorespiration is a wasteful process linked with C_3 cycle. It consumes ATP.
- It occurs in chloroplast, peroxisomes and mitochondria.

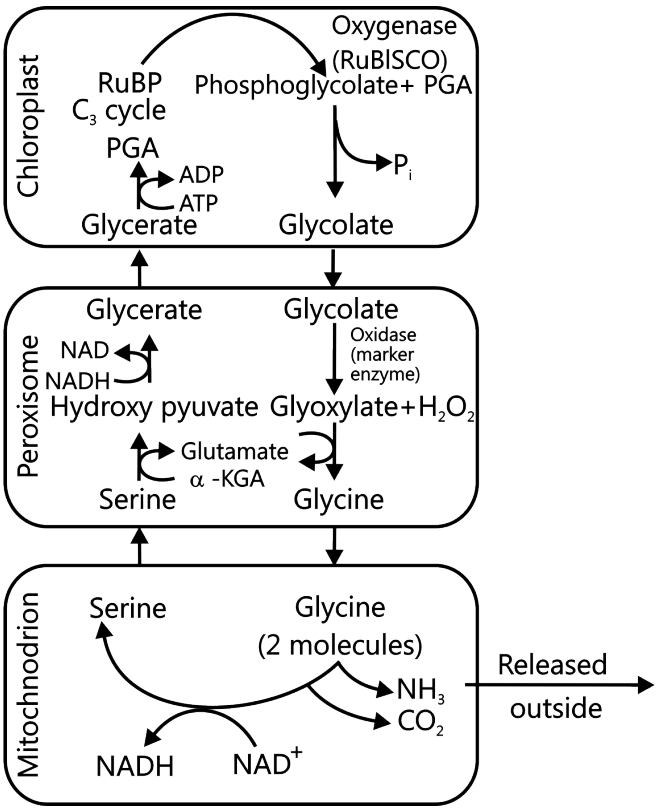

Figure 15.12: The C2 Cycle

TRY IT YOURSELF

1. PS II is involved in cyclic photophosphorylation. (True/False)
2. P 700 is involved in _____ photophosphorylation. (Cyclic/Non-cyclic/ both Cyclic and Non-cyclic)
3. C_4- plants are less efficient with respect to carbon fixation. (True/False)
4. Bundle sheath cells have large number of agranal chloroplasts. (True/False)
5. _____ is the first stable product in the C_3 cycle.
6. The full form of CAM is _____.
7. Describe photorespiration in short.

6. Factors Affecting Photosynthesis

- Law of limiting factors states then when the rapidity of a process is dependent on more than one factor, the rate at which the process occurs is controlled by the slowest factor.
- In case pf photosynthesis,water may be a limiting factor in dry regions, light may be limiting on cloudy days and in dense forests.

Factors-

(i) Light

- There is a linear relationship between light intensity and rate of photosynthesis at low light intensity.
- At extremely high light intensity photo-oxidation may occur and this may destroy the photosynthetic apparatus.
- Intensity of light, at which rate of photosynthesis, becomes equal to the rate of respiration in plants is known as light compensation point.
- Net photosynthesis or net primary productivity at this point is zero.

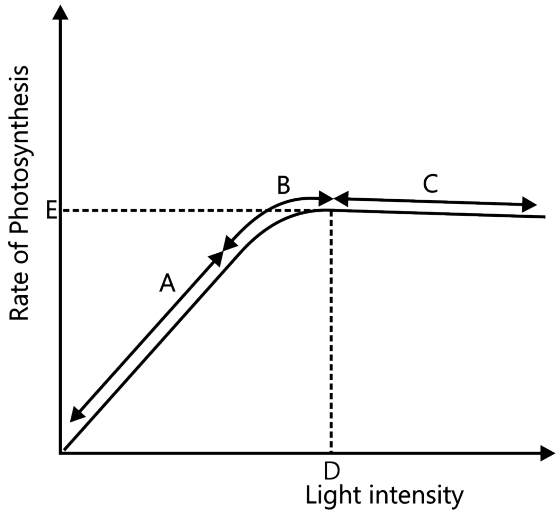

Figure 15.13: Photosynthesis-light dependence

(ii) Temperature

- Optimum temperature for C_3 plants for photosynthesis is 20°–25°C and 30°–40°C for C_4 plants.
- The rate of photosynthesis decreases at higher temperature due to denaturation of enzymes
- Dark reactions are more affected by temperature as compare to light reactions.

(iii) Concentration of CO_2 (Between 0.03% and 0.04%)

- An increase in CO_2 concentration upto 0.05% boosts the rate of photosynthesis
- Higher concentration of CO_2 is toxic to plants and also leads to closure of stomata.
- The CO_2 concentration at which CO_2 fixation in photosynthesis is equal to volume of CO_2 released in respiration when plant saturated with full light is called CO_2 compensation point.
- CO_2 compensation point for C_4 plants is 8 – 10 ppm, while for C_3 plants it is 40 – 100 ppm.

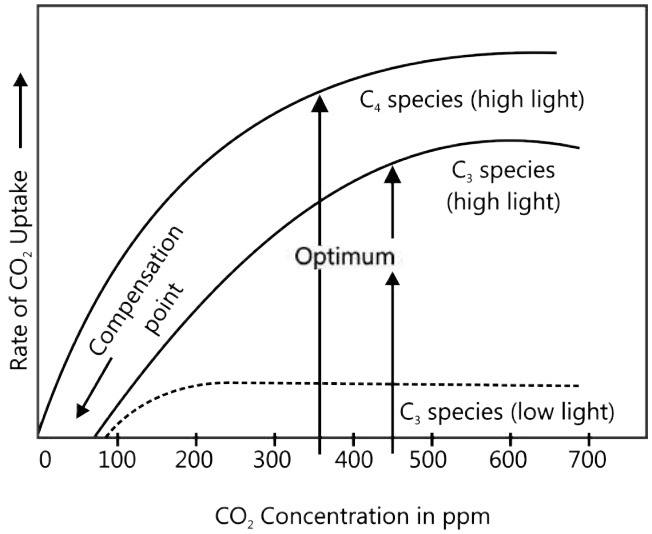

Figure 15.14: A graph of CO_2 uptake vs the CO_2 availability

(iv) Water

- Reduction in availability of water reduces the rate of photosynthesis.

(v) Plant factors

- Amount of chlorophyll present.
- Leaves- The leaf number, size, age and leaf orientation can affect the rate of photosynthesis

(vi) Inhibitors

- DCMU (Diuron/Dichlorophynyl Dimethyl Urea) CMU (Monuron), PAN, Atrazine, Simazime, Bromocil, Isocil inhibit electron flow between P-680 and PQ and thereby by inactivate PS II system.
- Diquat (herbicide), paraquate etc. inhibit electron flow between P-700 and Ferredoxin and thereby inactivate the PS I system.

7. Bacterial Photosynthesis

- Certain bacteria are capable for photosynthesis **e.g. – *Chlorobium* (Green sulphur), *Rhodospirillum*, *Rhodopseudomonas* (purple non-sulphur)**.
- Cyclic photophosphorylation is an important method in bacterial photosynthesis.
- PS II is absent. So non-cyclic photophosphorylation is absent.
- Pigment system of bacteria denoted by – B-890 or B-870
- Evolution of O_2 if any is not linked to bacterial photosynthesis, because water is not the H^+ donor. The donor may be hydrogen sulfide.

$$6\,CO_2 + 12\,H_2S \xrightarrow[\text{Pigments in chromatophores}]{\text{IR light}} C_6H_{12}O_6 + 6\,H_2O + 12S$$

Try It Yourself

1. Name some inhibitors of photosynthesis.
2. State one ill effect of excess light on photosynthesis.
3. Cyclic respiration is absent in bacteria. (True/False)
4. Bacteria give out O_2 during photosynthesis. (True/False)

Summary

- 'Photosynthesis is defined as the photo-biochemical/physicochemical mechanism, incorporating anabolic, reductive and endergonic processes carried out by green plants, in which complex, energy-rich organic compounds (carbohydrates such as sugars, starches) are synthesized from simple inorganic raw materials composed of water (H_2O) and carbon dioxide (CO_2) in presence of electromagnetic radiations (light or solar energy) and light capturing pigments (chlorophyll, carotenoids) with release of oxygen (O_2) as a byproduct.'
- Chlorophylls are the main photosynthetic pigments that harvest solar energy.
- Arnoff and Allen (1966) recognized 9 types of chlorophylls. Some of them are– (1) Chlorophyll-a; (2) Chlorophyll -b, (3) Chlorophyll –c etc.
- Chlorophyll-a and chlorophyll-b are the two main types of chlorophylls found in plants.
- Generally light energy absorbed by other photosynthetic pigment is transferred to chlorophyll-a.
- Carotenoids are yellow to orange lipid compounds. They occur in almost all higher plants.
- Carotenoids are of two types- carotenes and xanthophylls.
- Phycobilins are accessory pigments found in red algae and cyanobacteria.

- They have open chain tetrapyrrole structure.
- Quantasomes are units of photosynthesis.
- Absorption spectrum is represented as a graph obtained by plotting Absorption vs Wavelength for a particular pigment.
- Action spectrum is a graph showing the effectiveness of different wavelengths of light in stimulating the process under investigation.
- Photosystems are functional and structural units consisting of protein complexes involved in photosynthesis.
- They are located in the thylakoid membranes of plants and algae or in the cytoplasmic membrane of photosynthetic bacteria.
- There are two kinds of photosystems: Photosystem I and Photosystem II.
- Both photosystems I and II are required for oxygenic photosynthesis.

Cyclic photophosphorylation	Non-cyclic photophosphorylation
Only PS-I involved in cyclic process.	Both PS- II and PS-I works in non-cyclic process.
The e- expelled from chl-700 is cycled back.	The e- expelled from reaction centre is not cycled back. Its loss is compensated by e^- from H_2O.
Photolysis of water and evolution of O_2 does not take place.	Photolysis of water and evolution of O_2 takes place.
$NADP^+$ is not reduced.	$NADP^+$ is reduced to NADPH.
Activated by light of wavelength greater than 680 nm light.	Activated by light of wavelength 680 nm or sometimes less.

Characteristics	C_3 plants	C_4 plants
Cell type it. Which the Calvin cycle takes place	Mesophyll	Bundle sheath
Cell type in which the initial carboxylation reaction occurs	Mesophyll	Mesophyll
How many cell types does the leaf have that fix CO_2	One	Two
Which is the primary CO_2 acceptor	RuBP	PEP
Number of carbons in the primary CO_2 acceptor	5	3
Which is the primary CO_2 fixation product	PGA	OAA
No. of carbons in the primary CO_2 fixation product	3	4
Does the plant have Rubisco?	Yes	Yes

Characteristics	C_3 plants	C_4 plants
Does the plant have PEP case?	Yes	Yes
Which cells in the plant have Rubisco?	Mesophyll	Bundle sheath
CO_2 fixation rate under high light conditions	Medium	High
Whether photorespiration is present at low light intensities	Negligible	Negligible
Whether photorespiration is present at high light intensities	High	Negligible
Whether photorespiration would be present at low CO_2 concentrations	High	Negligible
Whether photorespiration would be present at high CO_2 concentrations	Negligible	Negligible
Temperature optimum	20-25°C	30-40°C
Examples	Wheat Rice	Maize Sugarcane Sorghum

- CAM pathway is observed in succulent xerophyte plants e.g. *Kalanchoe, Bryophyllum, Sedum, Kleinia* etc. Primary acceptor of CO_2 is PEP (Phosphoenol pyruvate).
- In CAM plants stomata are of scotoactive type (they open at night). Organic acids are produced during night and they are broken down during the day. Final CO_2 fixation (C_3 cycle) occurs in day time.
- Thus, CAM plants leave the stomata closed during the day. This highly reduces the water loss.
- Photorespiration is a pathway that is used to recycle the phosphoglycolate.
- Light, water, leaf anatomy, amount of chlorophyll, CO_2 etc. are factors that affect

EXERCISE

Objective Questions

Q.1 Oxygen which is liberated during photosynthesis comes from

(A) Carbon dioxide
(B) Water
(C) Chlorophyll
(D) Phosphoglyceric acid

Q.2 Nine-tenth of the world photosynthesis is carried out by

(A) Shrubs
(B) Herbs
(C) Trees
(D) Algae

Q.3 The process of taking in CO_2 by plants and releasing O_2 is termed as

(A) Transpiration
(B) Respiration
(C) Photosynthesis
(D) Endosmosis

Q.4 In plants during the process of photosynthesis

(A) CO_2 is taken in
(B) O_2 is taken in
(C) CO_2 is taken out
(D) O_2 is taken in and CO_2 is given out

Q.5 Our present day view regarding photosynthesis is that

(A) Converts light energy into chemical energy
(B) Creates useful energy
(C) Fixes CO_2 into carbohydrates
(D) Reverses the action of respiration

Q.6 In which of the following process, the light energy is converted into chemical energy

(A) Digestive action
(B) Respiration
(C) Photosynthesis
(D) Fermentation

Q.7 The dark reaction in photosynthesis is called so because

(A) It can only occur in dark
(B) It does not require light
(C) Both (A) and (B)
(D) None of these

Q.8 During photosynthesis the oxygen in glucose comes from

(A) Water
(B) Carbon dioxide
(C) O_2 in air
(D) Both from water and CO_2

Q.9 The law of limiting factor for photosynthesis was given by

(A) R. Hill
(B) Krebs
(C) Calvin
(D) Blackman

Q.10 The percentage of light energy utilized by higher plants, in the process of photosynthesis is

(A) 100%
(B) 10%
(C) 50%
(D) 1% – 2%

Q.11 Photosynthesis is most active in

(A) Sun light
(B) Yellow light
(C) Red light
(D) Green light

Q.12 If the CO_2 content of the atmosphere is as high as 300 parts per million

(A) All plants would be killed
(B) The plants would not grow properly
(C) Plants would grow for some time and then die
(D) The plants would thrive well

Q.13 R. Hill used a dye for his famous Hill-reaction

(A) Dischlorophenol indophenol (DCPIP)
(B) Sulphur green
(C) Methylene blue
(D) Eosine

Q.14 The isotope of carbon used extensively for studies in photosynthesis

(A) C^{13}
(B) C^{14}
(C) C^{15}
(D) C^{16}

Q.15 Which is the evidence to show that oxygen released in photosynthesis comes from water

(A) Isotopic oxygen (O^{18}) supplied as H_2O appears in the O_2 released in photosynthesis.

(B) Activated chloroplast in water released O_2 if supplied potassium ferrocyanide or some other reducing agent in the absence of CO_2.

(C) Photosynthetic bacteria use H_2O and CO_2 to make carbohydrates, H_2O and sulphur

(D) All of the above

Q.16 The path of CO_2 in the dark reactions of photosynthesis was successfully traced by the use of the following

(A) O_2^{18} (B) $C^{14}O_2$ (C) P^{32} (D) X-rays

Q.17 Discovery of Emerson effect has already shown the existence of

(A) Two distinct photosystems (B) Light and dark reactions of photosynthesis

(C) Photophosphorylation (D) Photorespiration

Q.18 The colour of light not utilized during photosynthesis is

(A) Violet (B) Green (C) Red (D) Blue

Q.19 During the process of photosynthesis the raw materials used are

(A) Glucose (B) Chlorophyll (C) Starch (D) CO_2 and H_2O

Q.20 Name the scientist, who first pointed out that plants purify foul air by bell jar experiment

(A) Willstatter (B) Robert Hooke

(C) Priestley (D) Lean Senebier

Q.21 Of the total amount of water absorbed by the plant, its actual percentage used during photosynthesis is

(A) 50% (B) 90% (C) 1% (D) 25%

Q.22 It is only the green part of the plant, which takes part in

(A) Respiration (B) Transpiration

(C) Photosynthesis (D) Osmosis

Q.23 Molls experiment explain that

(A) Carbon dioxide is essential for photosynthesis

(B) Chlorophyll and water are necessary for photosynthesis

(C) Light and water are essential for photosynthesis

(D) All the above are correct

Q.24 Which of the following is not a significance of photosynthesis?

(A) Glucose synthesis for most of consumer

(B) Increase in greenhouse effect

(C) Provides O_2 for synthesis of ozone umbrella

(D) Provides O_2 for cellular respiration

Q.25 Oxygen during photosynthesis comes from water was proved by O^{18} experiment

(A) Ruben and Kamen (B) Hill (C) Warburg (D) Blackman

Q.26 Name of the scientist who pointed out the importance of different wavelength of light using a green algae and aerobic bacteria

(A) Priestley (B) Ingen-Housz

(C) K.V. Thimann (D) Engleman

Q.27 Conversion of light energy into chemical energy within the plant body was first stated by ?

(A) Mayer and Anderson (B) Calvin

(C) Robert Mayer (D) Willstatter and Stoll

Q.28 The rate of photosynthesis decreases if the wavelength of visible light exceeds 680 nm. This was shown by which scientist and what is its reason?

(A) Black man – Law of limiting factors (B) Calvin and Benson – Photo oxidation

(C) Emerson and Arnold – Red drop (D) Ruben and Kamen – Photolysis

Q.29 Which of the following category of photosynthetic plants possess minimum transpiration ratio (TR)

(A) C_3 – plants (B) C_4 – plants

(C) CAM-plants (D) All the above

Q.30 The most effective wavelength of visible light in photosynthesis in the region of which of the following?

(A) Green (B) Yellow

(C) Red (D) Violet

Q.31 Which step of non-cyclic photophosphorylation is blocked by DCMU?

(A) Flow of e^- between PS I to Fd (B) Flow of e^- between cyto b_6 to cyto. f

(C) Flow of e^- between PC to PS I (D) Flow of e^- between PS II to PQ

Q.32 The radiant energy is stored in the form of chemical energy in

(A) NADP (B) Stored food (C) RNA (D) DNA

Q.33 How many quanta are required to reduce one molecule of CO_2 and produce one molecule of O_2 in green plant photosynthesis?

(A) 1 (B) 8 (C) 16 (D) 32

Q.34 Photosynthesis is

(A) Oxidative, exergonic, catabolic
(B) Redox-reaction, endergonic, anabolic
(C) Reductive, exergonic, anabolic
(D) Reductive, endergonic, catabolic

Q.35 The significance of light and chlorophyll in photosynthesis was discovered by

(A) Priestley
(B) Ingenhousz
(C) Englemann
(D) Blackman

Q.36 Which of the following carries out non-oxygenic photosynthetic?

(A) Cyanobacteria
(B) Crab grass
(C) Bacteria
(D) Wheat plant

Q.37 What is the unique process which has supported life on this planet?

(A) N_2 fixation
(B) Photosynthesis
(C) Protein synthesis
(D) Respiration

Q.38 Wavelength of light responsible for Emerson's enhancement effect

(A) Only 680 nm↑
(B) Only 680 nm↓
(C) Infra red wavelength
(D) Both 680 nm ↑ and 680 nm ↓

Q.39 The ''red – drop'' phenomenon is due to the disruption of the photo chemical activity of

(A) PS – I
(B) PS–I and PS–II both
(C) PS – II
(D) Carotenoids

Q.40 True for photosynthesis

(A) Oxidation of CO_2 and reduction of H_2O
(B) Process which connects the biotic and abiotic world
(C) Exergonic process
(D) Oxidation of Glucose

Q.41 Which of the following order is correct about the rate of photosynthesis?

(A) Blue > yellow > orange > red
(B) Blue > red > yellow > orange
(C) Red > blue > yellow > orange
(D) Yellow > orange > blue > red

Q.42 The process of photosynthesis takes place in

(A) Roots only (B) Shoot only

(C) All the cells of plant (D) Chlorophyll containing cells only

Q.43 Leaves appear green because

(A) They absorb green light (B) They reflect green light

(C) They absorb and reflect green light (D) They absorb green and reflects white light

Q.44 First of all which organism creates oxidizing atmosphere on earth?

(A) Cyanobacteria (B) Photosynthesis

(C) Ferns (D) Dicots

Q.45 The process of photo phosphorylation take place in

(A) Chloroplast (B) Ribosomes (C) Mitochondria (D) Cell-wall

Q.46 PS I occurs in

(A) Appressed part of granal thylakoids

(B) Appressed and non appressed part of grana thylakoids

(C) Stroma

(D) Stroma thylakoids and non-appressed part of grana thylakoids

Q.47 Photophosphorylation means synthesis of

(A) ATP from ADP (B) NADP (C) ADP from ATP (D) PGA

Q.48 Which one of the following pigment does not occurs in the chloroplast?

(A) Carotene (B) Xanthophyll

(C) Chlorophyll ‘b’ (D) Anthocyanin

Q.49 Start of manufacture of chlorophyll in a plant seedling is stimulated by

(A) Gibberellins (B) Indole acetic acid

(C) Kinin (D) Light

Q.50 Chlorophyll contains

(A) Fe (B) Mg (C) K (D) Mn

Q.51 Which pigment is water soluble?

(A) Chlorophyll (B) Carotene (C) Anthocyanin (D) Xanthophyll

Q.52 Chloroplasts fix

(A) Carbon dioxide (B) Oxygen

(C) Nitrogen (D) Hydrogen

Q.53 ATP formation during photosynthesis is termed

(A) Phosphorylation (B) Photophosphorylation

(C) Oxidative phosphorylation (D) Photolysis

Q.54 The main site for dark reaction of photosynthesis is

(A) Stroma (B) Grana

(C) Intergrana (D) Mitochondria

Q.55 What will be left if chlorophyll is burnt?

(A) Magnesium (B) Manganese

(C) Iron (D) Sulphur

Q.56 Chlorophyll is present

(A) In the grana of chloroplasts (B) On the surface of chloroplasts

(C) Dispersed through out the chloroplasts (D) In the stroma of chloroplasts

Q.57 Solar energy is converted to ATP in

(A) Mitochondria (B) Chloroplast

(C) Ribosome (D) Peroxisome

Q.58 In blue green algae photosynthesis takes place in

(A) Chloroplasts (B) Lamellisome

(C) Heterocysts (D) Carotene

Q.59 Condition necessary for photosynthesis are

(A) Light and suitable temperature (B) Chlorophyll and water

(C) Carbon dioxide (D) All of the above

Q.60 Photosynthesis is maximum during

(A) Continuous weak light (B) Continuous strong light

(C) Intermittent light (D) None of the above

Q.61 Process of photophosphorylation was first given by

(A) Hill (B) Willstatter and Stoll

(C) Arnon (D) Park and Biggins

Q.62 Which colour of light gives maximum absorption peak by chlorophyll 'a'?

(A) Blue light (B) Green light (C) Violet light (D) Red light

Q.63 Which scientists are related with light reaction and what is its site?

(A) Arnon and Hill, Grana

(B) Ruben and Kamen, stroma

(C) Willstatter, Stoll, inner membrane of chloroplast

(D) Calvin and Benson, outer membrane of chloroplast

Q.64 Presence of carotenes in chloroplast helps in

(A) ATP synthesis

(B) Transferring radiant energy into chemical energy

(C) Protecting chlorophyll molecules from photo oxidation

(D) Absorption of longer wavelength of light

Q.65 Ribulose bisphosphate carboxylase oxygenase (Rubisco) is located in

(A) Golgi bodies (B) Peroxisome

(C) Chloroplast (D) Mitochondria

Q.66 Which of the following photosynthetic bacteria have both PS-I and PS-II?

(A) Purple sulphur bacteria (B) Cyanobacteria

(C) Purple non sulphur bacteria (D) Green sulphur bacteria

Q.67 The site of oxygen evolution and photosynthetic phosphorylation in chloroplast is

(A) Grana (B) Matrix

(C) Surface of chloroplast (D) Inner wall of chloroplast

Q.68 The formula of chlorophyll 'a' is

(A) $C_{35}H_{72}O_5N_4Mg$
(B) $C_{55}H_{70}O_3N_4Mg$
(C) $C_{55}H_{72}O_5N_4Mg$
(D) $C_{51}H_{70}O_6N_4Mg$

Q.69 The number of pigment molecules in quantasome is

(A) 250 – 400
(B) 300 – 900
(C) 500 – 600
(D) 50 – 100

Q.70 The main difference between chlorophyll 'a' and 'b' is

(A) Chlorophyll 'a' is a linear chain compound and 'b' is branched chain

(B) Chlorophyll 'a' has no Mg^+ ion in centre of molecule

(C) In chlorophyll 'a' there is $–CH_3$ group whereas in 'b' it is –CHO group

(D) All of the above

Q.71 For chlorophyll formation in plants elements needed are

(A) Sodium and copper
(B) Calcium and potassium
(C) Iron and magnesium
(D) Iron and calcium

Q.72 Which one is the precursor of chlorophyll?

(A) Tryptophan
(B) Protochlorophyll
(C) Bacteriochlorophyll
(D) Bacterioviridin

Q.73 The role of chlorophyll in photosynthesis is

(A) Absorption of CO_2

(B) Absorption of light

(C) Absorption of light and photochemical decomposition of water

(D) Absorption of water

Q.74 Chloroplast contains maximum quantity of

(A) Pyruvic carboxylase
(B) Hexokinase
(C) RUBP carboxylase
(D) None of the above

Q.75 Chlorophyll 'a' is found in

(A) All O_2 releasing photosynthetic forms
(B) Only higher plants
(C) Higher plants that photosynthesize
(D) All photosynthetic eukaryotes

Q.76 In angiosperms, synthesis of chlorophyll occurs in presence of

(A) Phytochrome (B) Light

(C) Cytochrome (D) None of the above

Q.77 In pigment system I active chlorophyll is

(A) P-600 (B) P-680 (C) P-700 (D) P-720

Q.78 Chlorophyll 'e' is generally present in

(A) Thallophytes (B) Rhodophytes (C) Mycophytes (D) Xanthophytes

Q.79 In pigment system II the trapping centre of light energy is

(A) P-700 (B) P-680 (C) Carotene (D) Xanthophyll

Q.80 Basic structure of all chlorophyll comprises of

(A) Cytochrome system (B) Flavoproteins

(C) Porphyrin system (D) Plastocyanin

Q.81 The chemical formula of bacteriochlorophyll is

(A) $C_{55}H_{70}O_4N_4$ Mg (B) $C_{55}H_{72}O_5N_4$Mg

(C) $C_{55}H_{70}O_5N_4$ Mg (D) $C_{55}H_{74}O_6N_4$ Mg

Q.82 What is the byproduct of bacterial photosynthesis?

(A) O_2 (B) H_2O (C) S (D) H_2S

Q.83 Photosynthetic bacteria do not contain

(A) PS – I (B) PS – II (C) PS – I or PS – II (D) Quantasome

Q.84 In photosynthetic bacteria photosynthesis takes place in

(A) Chloroplast (B) Chromoplast (C) Chromatophores (D) Mesosomes

Q.85 What is the role of light in plants?

(A) Necessary for photosynthesis

(B) Controls growth and movement

(C) Controls distribution of hormones and flowering

(D) All of the above

Q.86 Photosynthetic units are referred as

(A) Quantasome (B) Oxysome

(C) Phycobillisome (D) F_1 – Particles

Q.87 Rubisco constitutes

(A) 4% of the chloroplast protein (B) 11% of the chloroplast protein

(C) 16% of the chloroplast protein (D) 25% of the chloroplast protein

Q.88 Bio-chemical phase in photosynthesis was first discovered by

(A) Calvin (B) Blackman (C) Arnon (D) Hill

Q.89 The accepted size of chlorophyll molecule is

(A) Head; 15 x 10 Åand Tail; 25 Å (B) Head: 20 x 20 Å and Tail: 25 Å

(C) Head: 10 x 10 Å and Tail: 15 Å (D) Head: 15 x 15 Å and Tail; 20 Å

Q.90 The photosynthetic pigment ''chlorophylls" are soluble in

(A) Water (B) Inorganic solvent

(C) Organic solvent (D) Water and organic solvent

Q.91 Which of the following chlorophyll is lack of phytol tail?

(A) Chl. 'a' (B) Chl. 'b' (C) Chl. 'c' (D) Chl. 'e'

Q.92 Photosynthetic pigment phycobilins are not associated with

(A) PS II (B) Cyanobacteria (C) PS I (D) All the above

Q.93 Percentage of chlorophyll in a normal chloroplast

(A) 5-10% (B) 40-50% (C) 65-75% (D) 90-95%

Q.94 The correct formula for carotene is

(A) $C_{40}H_{56}$ (B) $C_{40}H_{50}$ (C) $C_{40}H_{56}O_2$ (D) $C_{41}H_{56}O_3$

Q.95 Normally phycobilins occurs in

(A) Red algae (B) Blue green algae

(C) Rhodophyceae (D) All of the above

Q.96 Which of the following protein is most abundant on the earth?

(A) Catalase (B) Rubisco (C) Amylase (D) None of these

Q.97 Porphyrin is occurs in

(A) Chlorophyll (B) Hemoglobin (C) Cytochrome (D) All the above

Q.98 Universal photosynthetic chlorophyll is

(A) Chl-a (B) Chl-b (C) Chl-c (D) Chl-e

Q.99 Which of the following is the site of photolysis of water?

(A) Stroma of chloroplast (B) Cristae of chloroplast

(C) Ribosome of chloroplast (D) Lumen of thylakoid sacs

Q.100 Which one of the following is precursor of Protochlorophyll?

(A) Acetyl CoA (B) Succinyl CoA

(C) Oxaloacetic acid (D) α-ketoglutarate

Q.101 The first step in photosynthesis is

(A) Joining of three carbon atoms of from glucose

(B) Formation of ATP

(C) Ionization of water

(D) Excitement of an electron of chlorophyll by a photon of light

Q.102 The ultimate gain of light reaction is

(A) ATP and $NADPH_2$ (B) $NADPH_2$

(C) Only ATP (D) Only O_2

Q.103 Photophosphorylation is the process in which

(A) CO_2 and O_2unite

(B) Phosphoglyceric acid is produced

(C) Aspartic acid is formed

(D) Light energy is converted in to chemical energy by production of ATP

Q.104 Algae and other submerged plants buoyant in water during day time and sink at night, because

(A) They come upto enjoy some time

(B) They lose weight at night

(C) They become buoyant due to accumulation of O_2 as a result of photosynthesis

(D) They become light due to food material accumulation

Q.105 Which occurs during the light reaction of photosynthesis

(A) Chlorophyll is produced

(B) Water splits to form $2H^+$ and O_2

(C) CO_2 is given off as a waste

(D) Sugar is formed from CO_2 and water

Q.106 The function of ATP in photosynthesis is the transfer of energy from the

(A) Dark reaction to the light reaction

(B) Light reaction to the dark reaction

(C) Chloroplasts to mitochondria

(D) Mitochondria to chloroplasts

Q.107 In photosynthesis, hydrogen is transferred from the light reaction to dark reactions by

(A) DPN (B) DNA (C) ATP (D) NADP

Q.108 Which of the following element is a component of ferredoxin

(A) Copper (B) Manganese (C) Zinc (D) Iron

Q.109 During photochemical reaction of photosynthesis

(A) Liberation of O_2 takes place

(B) Formation of ATP and $NADPH_2$ take place

(C) Liberation of O_2 formation of ATP and $NADPH_2$ takes place

(D) Assimilation of CO_2 takes place

Q.110 Splitting of water in photosynthesis is called

(A) Dark reaction

(B) Photolysis

(C) Electron transfer

(D) Phototropism

Q.111 The product of hill reaction are

(A) ATP and $NADPH_2$ in chloroplast

(B) ATP and $NADPH_2$ in mitochondria

(C) Only oxygen

(D) A reduced substance $NADPH_2$, ATP and O_2 in chloroplast

Q.112 ADP + iP = ATP in grana is called

(A) Phosphorylation (B) Oxidative phosphorylation

(C) Photophosphorylation (D) Photolysis

Q.113 Which of the following is excited molecule during photosynthesis

(A) Chlorophyll (B) Oxygen (C) Carbon dioxide (D) Water

Q.114 $NADPH_2$ is also called

(A) Real power (B) Oxidising agent

(C) Power house of energy (D) Reducing power

Q.115 During ionization of H_2O, H^+ is ultimately captured by

(A) Chlorophyll (B) NADP (C) O_2 (D) Cytochrome

Q.116 At the time of ionization of H_2O which initially captures the electron

(A) Chlorophyll (B) NADP (C) OH^- (D) Cytochrome

Q.117 In cyclic photophosphorylation which one of the following is formed

(A) NADP and ATP (B) ATP

(C) $NADH_2$ and O_2 (D) $NADPH_2$, ATP and O_2

Q.118 Fixation of one CO_2 requires

(A) 6 $NADPH_2$ and 3 ATP (B) 2 $NADPH.H_2$ and 3 ATP

(C) 4 $NADPH.H_2$ and 3 ATP (D) 5 $NADP.H_2$ and 3 ATP

Q.119 Photo oxidation of water in photosynthesis is in association of

(A) Cytochrome b_6 (B) Pigment system – I

(C) Pigment system – II (D) Plastocyanin

Q.120 During ATP synthesis electron pass through

(A) Water (B) Cytochromes (C) O_2 (D) CO_2

Q.121 Which pigment system ultimately donates e- for the reduction of NADP

(A) PS II (B) PS I (C) CO_2 (D) Plastoquinone

Q.122 Respiration and photosynthesis both require

(A) Green cells (B) Sunlight (C) Cytochromes (D) Organic fuel

Q.123 Photosynthesis is an oxidation reduction process, the materials that is oxidized is

(A) CO_2 (B) NADP (C) H_2O (D) PGA

Q.124 Element which helps in electron transport in the process of photosynthesis is

(A) Zinc (B) Molybdenum (C) Boron (D) Manganese

Q.125 Photo oxidation of chlorophyll is called

(A) Intensification (B) Chlorosis (C) Solarization (D) Defoliation

Q.126 Thebyproduct of photosynthesis is

(A) CO_2 (B) Oxygen (C) Energy (D) Sugar

Q.127 The electron ejected by P680 in light reaction is initially accepted by

(A) Plastoquinone (B) ATP (C) Ferredoxin (D) P-700

Q.128 Decreased rate of photosynthesis at high concentration of O2 is referred to as

(A) Pasteur effect (B) Emerson effect

(C) Warburg effect (D) Richmond land effect

Q.129 Which element are present in OEC (oxygen evolving complex)

(A) Mn^{++} (B) Cl^{-} (C) Ca^{++} (D) All of the above

Q.130 Which one is Cu^{++} containing protein complex

(A) Ferredoxin (B) Plastocyanin

(C) Plastoquinone (D) Cytochrome

Q.131 Only pigment system I is concerned with

(A) Photolysis

(B) Cyclic photophosphorylation

(C) Non-cyclic photophosphorylation

(D) Oxidative phosphorylation

Q.132 The important role of PS – II in photosynthesis is

(A) To cause photolysis of water (B) To release energy

(C) To trap and assimilate CO_2 (D) To reduce NAD to NAD. H_2

Q.133 The first electron carrier molecule from P700 to $NADP^+$ is believed to be

(A) Cytochrome (B) Cu protein/plastocyanin

(C) FeS protein/Ferredoxin (D) Fe-Mg Protein

Q.134 In plants, hill reaction occurs

(A) All the time

(B) Only in day time

(C) Only when the plants are grown in cold climate of hills

(D) When the plant carries out uphill task of salt absorption and food translocation

Q.135 Pigment system II occurs in

(A) Grana (B) Stroma (C) Matrix (D) Oxysomes

Q.136 The excess energy of e- (in ETS) is used in the synthesis of

(A) ATP from ADP and Pi (B) $NADPH_2$ from NADP

(C) Organic compounds (D) ADP from ATP

Q.137 During photosynthesis

(A) Water is reduced and CO_2 is oxidized

(B) CO_2 is reduced and water is oxidized

(C) Both CO_2 and water get reduced

(D) Both CO_2 and water get oxidized

Q.138 Photolysis is related to

(A) Calvin cycle (B) H.S.K cycle

(C) Cyclic photophosphorylation (D) Non cyclic flow of electrons

Q.139 Connecting link between light phase and dark phase of photosynthesis

(A) Only ATP (B) Only $NADH_2$ (B) Only $NADPH_2$ (D) Both (A) and (C)

Q.140 When the two pigment systems absorb light in what direction does the energy flow between them

(A) PS-I -> PS-II (B) PS-II -> PS-I

(C) PS-II = PS-I (D) None of the above

Q.141 Which photosynthetic pigment converts nascent oxygen to molecular oxygen

(A) Chlorophyll-a (B) Carotenoids

(C) Phycobilins (D) Chlorophyll-b

Q.142 Which cofactor is necessary for photolysis of water.

(A) Mg (B) Mn (C) Fe (D) Cu

Q.143 Who proposed Z-scheme of light reaction

(A) Arnon (B) Calvin and Bensen

(C) Emerson and Arnon (D) Blackman

Q.144 Detail study of pigment systems made by

(A) Robert Hill (B) H.P. Nanda (C) Govindji (D) Emmerson

Q.145 In photosynthesis CO_2 combines with

(A) RUDP/RUBP (B) ATP (C) ADP (D) PGA

Q.146 During the dark reactions of photosynthesis

(A) Water splits (B) CO_2 is reduced to organic compounds

(C) Chlorophyll is activated (D) C_6 sugar is broken into three carbon sugars

Q.147 The first stable product of photosynthesis in C_3 plants is

(A) 3-phosphoglyceric acid (B) Dihydroxyacetone phosphate

(C) Fructose-1, 6-diphosphate (D) Ribulose-1, 5-di phosphate

Q.148 During photosynthesis when PGA is changed into phosphoglyceraldehyde which of the following reaction occurs

(A) Oxidation (B) Reduction (C) Electrolysis (D) Hydrolysis

Q.149 Which one of the following is a C_4 plant

(A) Papaya (B) Potato (C) Maize (D) Pea

Q.150 Carbon refixation in C_4 plants occurs in chloroplasts of

(A) Palisade tissue (B) Spongy Mesophyll

(C) Bundle sheath cells (D) Guard cells

Q.151 Tropical plants like sugarcane show high efficiency of CO_2 fixation because of

(A) Calvin cycle (B) Hatch – Slack cycle

(C) Cyclic photophosphorylation (D) TCA Cycle

Q.152 "Kranz" type of Anatomy is found in

(A) C_4 plant (B) C_3 plant

(C) Succulents (D) None of the above

Q.153 Carbon dioxide acceptor in C_4 plants is

(A) Phosphoenol pyruvic acid (PEP) (B) Ribulose-1, 5-di phosphate

(C) NADP (D) Ribulose -5- phosphate

Q.154 What is the first stable intermediate product of photosynthesis

(A) Glucose (B) Formaldehyde

(C) Phosphoglyceric acid (D) PGAL

Q.155 All the reactions from the reduction of CO_2 to the formation of sugar are included in

(A) Light reaction (B) Photolysis

(C) Dark reaction (D) Hill reaction

Q.156 Ribulose diphosphate carboxylase enzyme, catalyze the carboxylation reaction between

(A) CO_2 and ribulose-1, 5-diphosphate (B) Oxaloacetic acid and acetyl Co-A

(C) PGA and dihydroxyacetone phosphate (D) Ribulose diphosphate and phosphate glyceraldehyde

Q.157 Which of the following is C-4 plants

(A) Maize (B) *Atriplex* (C) Sugarcane (D) All of the above

Q.158 "Kranz Anatomy" is found in

(A) Flower (B) Seed (C) Leaves (D) Stem

Q.159 C_4 plants are adapted to

(A) Hot and dry climate (B) Temperate climate

(C) Cold and dry climate (D) Hot and humid climate

Q.160 C_4 plants are found among

(A) Only Gramineae (B) Only monocot

(C) Only dicot (D) Monocots as well as dicots

Q.161 In case of C-4 pathway, in the first step is

(A) CO_2 combines with RUDP (B) CO_2 combines with PGA

(C) CO_2 combines with PEP (D) CO_2 combines with RMP

Q.162 The enzyme which catalyzes the photosynthetic C_4 cycle is

(A) RUDP carboxylase (B) PEP carboxylase

(C) Carbonic anhydrase (D) None of these

Q.163 The family in which many plants are C_4 type

(A) Malvaceae (B) Solanaceae

(C) Crucifereae (D) Gramineae

Q,164 In dark reaction, first reaction is the

(A) Carboxylation (B) Decarboxylation

(C) Dehydrogenation (D) Deamination

Q.165 Number of ATP molecules required for regeneration phase of RUBP during synthesis of 1 glucose molecule

(A) 6 (B) 12 (C) 18 (D) 30

Q.166 Which of the following is likely to be the first substance that a green plant makes in photosynthesis

(A) A simple sugar (B) Starch

(C) Fats (D) Proteins

Q.167 Isotopes employed to study the process of photosynthesis reaction

(A) S^{35} and P^{32} (B) C^{14} and O^{18} (C) N^{14} and Co^{60} (D) N^{14} and O^{18}

Q.168 Chloroplast is present in bundle sheath cells of

(A) C_3-plants (B) C_4-plants

(C) CAM plants (D) Photorespiring plants

Q.169 CO_2 is accepted by RUBP in C_4 plants in

(A) Mesophyll cells (B) Bundle sheath cells

(C) Stomatal guard cells (D) Epidermal cells

Q.170 How many type of photosynthetic cells occur in C_4 plant is

(A) One type (B) Two type (C) Four type (D) Eight type

Q.171 Most efficient photosynthesis and presence of bundle sheath chloroplast are characteristics of

(A) C_3-plants (B) C_2 plants (C) C_4 plants (D) CAM plants

Q.172 In C_4 pathway the fixation of CO_2 by PEPCase occurs in

(A) Palisade tissue (B) Mesophyll (C) Bundle sheath (D) Guard cell

Q.173 Synthesis of fructose in C_4 pathway occurs in the chloroplast of

(A) Spongy mesophyll (B) Bundle sheath cells

(C) Guard cell (D) Palisade tissue

Q.174 C_2 and C_3 cycles predominantly operates in

(A) Cytoplasm and mitochondria (B) Mitochondria and peroxisome

(C) Peroxisome and stroma (D) Stroma and grana of a chloroplast

Q.175 In addition to the 12 molecules of $NADPH_2$ the energy required for the synthesis of one mole of hexose by C_3 and C_4 pathway is

(A) 18 molecules of ATP

(B) 30 molecules of ATP

(C) 18 and 30 molecules of ATP respectively

(D) 30 and 18 molecules of ATP respectively

Q.176 How many molecules of water are needed by a green plant to produce one molecule of hexose/ reduce 6 molecules of CO_2

(A) 6 (B) 12 (C) 24 (D) Only one

Q.177 How much energy in terms of ATP equivalents is consumed in the photosynthetic production of a mole of hexose

(A) 36 ATP equivalents (B) 38 ATP equivalents

(C) 40 ATP equivalents (D) 54 ATP equivalents

Q.178 How many molecules of Water would be consumed to support one Calvin cycles

(A) One (B) Two (C) Four (D) Six

Q.179 How many Calvin cycles would generate one molecules of glucose/hexose

(A) One cycle (B) Three cycles (C) Six cycles (D) Twelve cycles

Q.180 CAM – plants are mainly

(A) Succulent xerophyte (B) Hydrophytes

(C) Epiphytes (D) None of the above

Q.181 Hatch and slack pathway occurs in

(A) *Amaranthus* (B) *Atriplex rosea*

(C) *Saccharum* (D) All of the above

Q.182 The first stable product of Calvin cycle and HSK-cycle are

(A) 4-C and 3-C compounds (B) 4-C and 6-C compounds

(C) 3-C and 4-C compounds (D) 5-C and 4-C compounds

Q.183 Which one is the first seven carbon compound in the C_3 cycle

(A) SHP (B) DHAP (C) SHDP (D) FDP

Q.184 Which compound is four carbon compound in the C_3 cycle

(A) Erythrose-P (B) DHAP (C) PGAL (D) OAA

Q.185 Term-Apoplast and symplast first used by

(A) Clark (B) Munch (C) Dixon (D) Lungedardh

Q.186 Which of the following is used during discovery of Calvin cycle

(A) *Spirogyra* (B) *Volvox* (C) *Chlamydomonas* (D) *Chlorella*

Q.187 Primary receptor of CO_2 in photosynthesis is

(A) Phosphoric acid (B) Ribulose phosphate

(C) Glucose (D) Ribulose -1, 5-biphosphate

Q.188 In photosynthesis energy from light reaction to dark reaction is transferred in the form of

(A) ADP (B) ATP (C) RUDP (D) Chlorophyll

Q.189 The rate of photosynthesis does not depend upon

(A) Light duration (B) Light intensity

(C) Light quality (colour) (D) Temperature

Q.190 Optimum temperature of photosynthesis is

(A) 10-15°C (B) 20-25°C (C) 20-35°C (D) 35-50°C

Q.191 Which one of the following have high CO_2 compensation point

(A) C_2 plants (B) C_3 plants (C) C_4 plants (D) Alpine herbs

Q.192 Solarization is a process in which

(A) Sugar are formed with the help of solar energy

(B) Chlorophyll is formed

(C) Destruction of chlorophyll and ultimate death of protoplasmic components

(D) Mobilization of light energy

Q.193 Accumulation of food in assimilatory cells results in

(A) Increase in the rate of photosynthesis

(B) Decrease in the rate of photosynthesis

(C) No effect

(D) May increase or decrease

Q.194 The principle of limiting factor was given by

(A) Hill (B) F.F. Blackman

(C) Willstatter and Stoll (D) Calvin

Q.195 Etiolated plants are formed due to lack of

(A) Light (B) Hg (C) Fe (D) Mg

Q.196 During day light hours, the rate of photosynthesis is higher than that of respiration and the ration of oxygen produced to that of consumed is

(A) 10: 1 (B) 5: 1 (C) 1: 1 (D) 50: 1

Q.197 Substrate for photorespiration is

(A) Serine (B) Glycolate (C) Indole acetic acid (D) Malic acid

Q.198 Generally atmo. CO_2 is not limiting for hydrophytes

(A) Mesophytes plants fix H_2S in their photosynthesis

(B) These plants obtain CO_2 from water in the form of HCO_3^-

(C) Glucose is not required for their respiration

(D) All the above

Q.199 What is called ''Warburg's effect'' on photosynthesis

(A) Low rate of process due to O_2 supply

(B) Low rate of the process due to CO_2 supply

(C) Both (A) and (B)

(D) None of the above

Q.200 Bacterial photosynthesis involves

(A) PS-I only (B) PS-II only

(C) Both PS-I and PS-II (D) None of the above

Q.201 Photorespiration occurs in

(A) Mitochondria (B) Chloroplast

(C) Peroxisome (D) Cytoplasm

Q.202 What is C_2 cycle

(A) Glycolate Cycle (B) Calvin cycle

(C) Kreb's cycle (D) TCA – cycle

Q.203 Drosera is a photosynthetic plant but still captures insects why ?

(A) Grown in N_2 rich soil

(B) Grown in N_2 deficient soil

(C) It is connecting plant between plants and animals

(D) Insects helps in its pollination

Q.204 Plants which exhibit photorespiration are

(A) C_4 plants (B) C_3 plants (C) CAM plants (D) Alpine plants

Q.205 Glycolate accumulates in chloroplast at

(A) Low temperature (B) Low CO_2

(C) Visible light illumination (D) High CO_2

Q.206 Which of the following plants are low CO_2 compensation plants

(A) C_3 plants (B) C_4 plants (C) C_2 plants (D) Alpine plants

Q.207 In photorespiring plants the atmospheric CO_2 is fixed via

(A) HSK-cycle (B) Kreb's cycle (C) Calvin cycle (D) Glycolate cycle

Q.208 Compensation point means

(A) When the rate of photosynthesis is equal to rate of respiration

(B) When there is neither photosynthesis nor respiration

(C) When the entire food manufactured in photosynthesis remains unutilized

(D) When availability of water equalize with necessity of water

Q.209 At the compensation point there will not be

(A) Any photosynthesis

(B) Any gaseous exchange between the plant and its environment

(C) Any respiration in plants

(D) Loss in weight of the plant in dark

Q.210 What does not occur in photorespiration

(A) Utilization of O_2 (B) Production of CO_2

(C) Synthesis of ATP (D) All the above

Q.211 DCMU is an inhibitor of

(A) PS-I (B) PS-II (C) Calvin cycle (D) Kreb's cycle

Q.212 Which of the following plants can carry out photosynthesis even at – 20°C/below freezing point

(A) Palms (B) Marine algae

(C) Diatoms (D) Lichens

Q.213 Photorespiration occur during

(A) Respiration (B) Photosynthesis

(C) Transpiration (D) Translocation

Q.214 Photorespiration is discovered by

(A) Decker and Tio (B) Van Sachs

(C) Rouhani (D) O'Leary

Q.215 Photorespiration is favored by

(A) High light intensity (B) High temperature

(C) High O_2 concentration (D) All of the above

Q.216 Photorespiration does not occur in

(A) C-4 plants (B) C-3 plants (C) C-2 plants (D) None of these

Q.217 What is the value of temperature coefficient (Q_{10}) for dark reaction

(A) 1 (B) 2 or 3 (C) Both (A) and (B) (D) None of the above

Q.218 Main factor which limits the rate of photosynthesis

(A) Chlorophyll (B) Light (C) CO_2 (D) Water

Q.219 Photosynthetic bacteria differ from green plants in

(A) Nature of their pigments

(B) Type of electron donors

(C) Photosynthetic process being non-oxygenic

(D) All of the above

Previous Years' Questions

Q.1 During photosynthesis, oxygen is evolved from ***[MP PMT 2002]***

(A) H_2S (B) H_2O (C) CO_2 (D) HCO_3

Q.2 Bacteriochlorophyll differs from chlorophyll 'a' in having ***[RPMT 2003]***

(A) One pyrrole nucleus with one hydrogen

(B) One pyrrole nucleus with two hydrogen

(C) One pyrrole nucleus with three hydrogen

(D) One pyrrole nucleus with four hydrogen

Q.3 In chlorophyll molecule ''Mg'' in situated in ***[AIPMT 2003]***

(A) Centre of porphyrin ring (B) Corner of porphyrin

(C) In phytol tail (D) In isocyclic ring

Q.4 Which one of the following concerns with photophosphorylation ***[AIPMT 2003]***

(A) $ADP + AMP \xrightarrow{\text{Lightenergy}} ATP$

(B) $ADP + \text{Inorganic } PO_4 \xrightarrow{\text{Lightenergy}} ATP$

(C) $ADP + \text{Inorganic } PO_4 \longrightarrow ATP$

(D) $AMP + \text{Inorganic } PO_4 \longrightarrow ATP$

Q.5 Hill reaction occurs in ***[AIIMS 2003]***

(A) High altitude plants (B) Total darkness

(C) Presence of ferricyanide (D) Absence of water

Q.6 Which of the following absorb light energy for photosynthesis ***[AIPMT 2002]***

(A) Chlorophyll (B) Water molecule (C) O_2 (D) RUBP

Q.7 The enzyme that fixes atmospheric CO_2 in C_4 plants is ***[AIPMT 2003]***

(A) PEP carboxylase (B) Hexokinase

(C) RUBP oxygenase (D) Hydrogenase

Q.8 Bundle sheath chloroplast of C_4 plant are ***[KCET 2003]***

(A) Large and agranal (B) Large and granal

(C) Small and agranal (D) Small and granal

Q.9 Photorespiration in C_3 plants starts from ***[AIIMS 2003]***

(A) Phosphoglycerate (B) Glycerate

(C) Glycine (D) Phosphoglycolate

Q.10 Photorespiration is favored by ***[RRMT 2004]***

(A) Low light intensity (B) Low O_2 and high CO_2

(C) Low temperature (D) High O_2 and low CO_2

Q.11 The substrate of photorespiration is ***[MP PMT 2002]***

(A) Glycolate (B) Glucose (C) Pyruvic acid (D) Acetyl CO-A

Q.12 Tracer elements are ***[MP PMT 2002]***

(A) Micro-elements (B) Macro-elements (C) Radio-isotopes (D) Vitamins

Q.13 Choose the correct match ***[AIPMT 2002]***

Bladderwort, sundew, Venus flytrap

(A) Nepenthese, dionea, Drosera (B) Nepenthese, Utricularia, Vanda

(C) Utricularia, Drosera, Dionea (D) Dionea, Trapa, Vanda

Q.14 Which one of the following is wrong in relation to photorespiration ***[AIPMT 2003]***

(A) It occurs in chloroplasts (B) It occurs in daytime only

(C) It is a characteristic of C_4 plants (D) It is a characteristic of C_3 plants

Q.15 Plants adapted to low light intensity have ***[AIPMT 2004]***

(A) Leaves modified to spines

(B) Large photosynthetic unit size than the sun plants

(C) Higher rate of CO2 fixation than the sun plants

(D) More extended root system

Q.16 In chloroplasts, chlorophyll is present in the ***[AIPMT 2004]***

(A) Stroma (B) Outer membrane

(C) Inner membrane (D) Thylakoids

Q.17 Which one of the following categories of organisms do not evolve oxygen during photosynthesis ***[AIIMS 2004]***

(A) Red algae (B) Photosynthetic bacteria

(C) C_4- plants with Kranz anatomy (D) Blue green algae

Q.18 Which pair is wrong ***[AIPMT 2001]***

(A) C_3 plant-maize (B) Calvin cycle PGA

(C) Hatch slack cycle (D) C_4 plant Kranz anatomy

Q.19 Chlorophyll in chloroplasts is located in ***[AIPMT 2005]***

(A) Grana (B) Pyrenoid (C) Stroma (D) Both grana and stroma

Q.20 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 ***[AIPMT 2005]***

(A) Two (B) Six (C) Zero (D) Twelve

Q.21 Carbohydrates, the most abundant biomolecules on earth, are produced by ***[AIPMT 2005]***

(A) All bacteria, fungi and algae

(B) Fungi, algae and green plant cells

(C) Some bacteria, algae and green plants cells

(D) Viruses, fungi and bacteria

Q.22 Photosynthetic Active Radiation (PAR) has the following range of wavelengths ***[AIPMT 2005]***

(A) 400-700 nm (B) 450-920 nm (C) 340-450 nm (D) 500-600 nm

Q.23 In light reaction of photosynthesis oxygen comes from ***[RPMT 2005]***

(A) Water (B) CO_2 (C) Soil (D) Atmosphere

Q.24 Product of light reaction of photosynthesis is ***[RPMT 2005]***

(A) Carbohydrate (B) ATP

(C) NADP and O_2 (D) $NADPH_2$, ATP and O_2

Q.25 During photorespiration, the oxygen consuming reaction(s) occur in ***[AIPMT 2006]***

(A) Grana of chloroplasts and peroxisomes

(B) Stroma of chloroplasts

(C) Stroma of chloroplasts and mitochondria

(D) Stroma of chloroplasts and peroxisomes

Q.26 The first acceptor of electrons from an excited chlorophyll molecule of photosystem II is ***[AIPMT 2007]***

(A) Quinone (B) Cytochrome

(C) Iron-sulphur protein (D) Ferredoxin

Q.27 In the leaves of C_4 plants, malic acid formation during CO_2 fixation occurs in the cells of ***[AIPMT 2007]***

(A) Epidermis (B) Mesophyll (C) Bundle sheath (D) Phloem

Q.28 In leaves of C_4 plants malic acid synthesis during CO_2 fixation occurs in ***[AIPMT 2008]***

(A) Bundle sheath (B) Guard cells

(C) Epidermal cells (D) Mesophyll cells

Q.29 The C_4 plants are photosynthetically more efficient than C_3 plants because ***[AIPMT 2008]***

(A) The CO_2 efflux is not prevented

(B) They have more chloroplasts

(C) 2 CO_2 compensation point is more

(D) CO_2 generated during photorespiration is trapped and recycled through PEP carboxylase

Q.30 Electron from excited chlorophyll molecule of photosystem II are accepted first by ***[AIPMT 2008]***

(A) Quinone (B) Ferredoxin

(C) Cytochrome-b (D) Cytochrome-f

Q.31 Oxygenic photosynthesis occurs in ***[AIPMT 2009]***

(A) Oscillatoria (B) Rhodospirillum

(C) Chlorobium (D) Chromatium

Q.32 Cyclic photophosphorylation results in the formation of ***[AIPMT 2009]***

(A) ATP and NADPH (B) ATP, NADPH and O_2

(C) ATP (D) NADPH

Q.33 PGA as the first CO2 fixation product was discovered in photosynthesis of ***[AIPMT pre 2010]***

(A) Bryophyte (B) Gymnosperm (C) Angiosperm (D) Alga

Q.34 C_4 plants are more efficient in photosynthesis than C_3 plants due to ***[AIPMT pre 2010]***

(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

Q.35 Read the following four statements, A, B, C and D and select the right option having both correct statements ***[AIPMT mains 2010]***

Statements

(1) Z scheme of light reaction takes place in present of PSI only

(2) Only PSI is functional in cyclic photophosphorylation

(3) Cyclic photophosphorylation results into synthesis of ATP and $NADPH_2$

(4) Stroma lamellae lack PSII as well as NADP

Options:

(A) 1 and 2 (B) 2 and 3 (C) 3 and 4 (D) 2 and 4

Q.36 CAM helps the plants in ***[AIPMT pre 2011]***

(A) Conserving water (B) Secondary growth

(C) Disease resistance (D) Reproduction

Q.37 In Kranz anatomy, the bundle sheath cells have ***[AIPMT mains 2011]***

(A) Thick walls, many intercellular spaces and few chloroplasts

(B) Thin walls, many intercellular spaces and no chloroplasts

(C) Thick walls, no intercellular spaces and large number of chloroplasts

(D) Thin walls, no intercellular spaces and several chloroplasts

Q.38 A process that makes important difference between C3 and C4 plants is ***[AIPMT pre 2012]***

(A) Photosynthesis (B) Photorespiration

(C) Transpiration (D) Glycolysis

Q.39 The correct sequence of cell organelles during photorespiration is ***[AIPMT pre 2012]***

(A) Chloroplast-mitochondria-peroxisome

(B) Chloroplast-vacuole-peroxisome

(C) Chloroplast-Golgi bodies-mitochondria

(D) Chloroplast-Rough endoplasmic reticulum-Dictyosomes.

Q.40 In C_3 plants, the first stable product of photosynthesis during the dark reaction is ***[AIPMT 2004]***

(A) Phosphoglyceraldehyde (B) Malic acid

(C) Oxaloacetic acid (D) 3-phosphoglyceric acid

Q.41 What is common between chloroplasts, chromoplasts and leucoplasts: ***[AIIMS 2008]***

(A) Presence of pigments (B) Possession of thylakoids and grana

(C) Storage of starch, proteins and lipids (D) Ability to multiply by a fission like process

Q.42 Structurally chlorophyll a and b are different as: ***[J and K 2009]***

(A) Chl a has a methyl group and Chl b has an aldehyde group

(B) Chl a has a carboxyl group and Chl b has an aldehyde group

(C) Chl a has an aldehyde group and Chl b has a methyl group

(D) Chl a has an ethyl group and Chl b has an aldehyde group

Q.43 Which one does not occur in cyclic photophosphorylation? ***[J and K 2009]***

(A) Oxygen is not given off (B) Water is not consumed

(C) Only photosystem-I is involved (D) NADPH formation

Q.44 In higher plants, the shape of the chloroplasts is: ***[DUMET 2009]***

(A) Discoid (B) Cup shaped (C) Girdle shaped (D) Reticulate

Q.45 In C4 plants, the bundle sheath cells: ***[DUMET 2009]***

(A) Have thin walls to facilitate gaseous exchange (B) Have large intercellular spaces

(C) Are rich in PEP carboxylase (D) Have a high density of chloroplasts

Q.46 Kranz anatomy is observed in: ***[AFMC 2009]***

(A) C2 plants (B) C3 plants (C) C4 plants (D) CAM plants

Q.47 Primary CO_2 acceptor of CAM plant: ***[UP-CPMT2009]***

(A) OAA (B) PGA (C) PEP and RuBP (D) Citric add

Q.48 First stable compound in C_3 plant is: ***[UP-CPMT2009]***

(A) PGA (B) OAA (C) RuBP (D) PEP

Q.49 Stomata of CAM plants: ***[UP-CPMT2009]***

(A) Are always open (B) Open during the day and close at night

(C) Open during the night and close during the day (D) Never open

Q.50 Stomata in the chloroplasts of higher plants contain: ***[CBSE 2009]***

(A) Light independent reaction enzymes (B) Light dependent reaction enzymes

(C) Ribosomes (D) Chlorophyll

Q.51 Oxygenic photosynthesis occurs in: ***[CBSE 2009]***

(A) Chromatium (B) Oscillatoria (C) Rhodospirillum (D) None of above

Q.52 The active component of photosystem-I is composed of: ***[AMU 2011]***

(A) Chlorophyll a with absorption peak at 680 nm

(B) Chlorophyll a with absorption peak at 700 nm

(C) Chlorophyll h with absorption peak at 680 nm

(D) Chlorophyll a and h with absorption peak at 700 nm

Q.53 In photorespiration, the cell organelles involved are: ***[AMU 2011]***

(A) Chloroplast and mitochondrion (B) Chloroplast only

(C) Chloroplast, mitochondrion and ribosome (D) Chloroplast, mitochondrion and peroxisome

Q.54 The conversion of phosphoglyceric acid to phosphoglyceraldehyde during photosynthesis can be described as: ***[AMU 2011]***

(A) Oxidation (B) Hydrolysis (C) Electrolysis (D) Reduction

Q.55 ATP can be formed in the photosynthesizing plant cells by: ***[AMU 2011]***

(A) Photophosphorylation (B) Oxidative phosphorylation

(C) Substrate level phosphorylation (D) All of the above

Q.56 Energy released during movement of electrons through the photosystems in photosynthesis is used to drive protons across the membrane against concentration gradient. As a result the protons accumulate in: ***[AMU 2011]***

(A) Thylakoid lumen (B) Stroma

(C) Intrathylakoid space (D) Stromal lamella

Q.57 The first event in photosynthesis is: ***[AMU 2011]***

(A) Photoexcitation of chlorophyll and electron emission

(B) Photolysis of water

(C) Release of oxygen

(D) Synthesis of ATP

Q.58 Rubisco is the most abundant enzyme in the world and present in very high concentration in chloroplasts. It is required in very high concentration for photosynthesis because it: ***[AMU 2011]***

(A) Is a very slow acting enzyme (B) Also acts as an oxygenase

(C) Catalyzes a reversible reaction (D) Is degraded very rapidly

Q.59 The enzyme, sucrose synthase, catalyzes the synthesis of sucrose from: ***[AMU 2011]***

(A) UDPG + fructose (B) UDPF + glucose

(C) UDPG + glucose-6-phosphate (D) UDPG + fructose-6-phosphate

Q.60 Light reaction of photosynthesis occurs inside: ***[J&K 2011]***

(A) Stroma (B) Grana

(C) Endoplasmic reticulum (D) Cytoplasm

Q.61 A reduction in the quantity of oxygen evolution during photosynthesis may be observed at: ***[J&K 2011]***

(A) Light having wave length more than 680 nm

(B) Light having wave length less than 680 nm

(C) Light having wave length 560 nm

(D) Light having wave length less than 360 nm

Q.62 Plants requiring low light intensity for optimum photosynthesis is called: ***[J&K 2011]***

(A) Heliophytes (B) Pteridophytes (C) Sciophytes (D) Bryophytes

Q.63 Sunken stomata are usually found in: ***[J&K 2011]***

(A) C3 plants (B) CAM plants (C) Insectivorous plants (D) Phanerogams

Q.64 Select the incorrect matched pair with regard to C_4 cycle: ***[Kerala 2011]***

(A) Primary CO_2 fixation product - PGA

(B) Site of initial carboxylation - mesophyll cells

(C) Primary CO_2 acceptor - PEP

(D) C_4 plant - maize

(e) Location of enzyme Rubisco - Bundle sheath cells

Q.65 In C_3 cycle for the fixation of every CO_2 molecule, the reduction and regeneration steps require: ***[Kerala 2011]***

(A) 3 ATP and 2 $NADPH_2$ (B) 2 ATP and 2 $NADPH_2$

(C) 2 ATP and 3 $NADPH_2$ (D) 3 ATP and 3 $NADPH_2$

(e) 3 ATP and 1 $NADPH_2$

Q.66 Which of the following is formed during photorespiration? ***[Kerala 2011]***

(A) Sugar (B) Phosphoglycolate (C) NADPH

(D) ATP (E) Oxaloacetate

Q.67 Which of the following statements is true with regard to the light reaction of photosynthesis? ***[Kerala 2011]***

(A) In PSII the reaction centre chlorophyll a has an absorption peak at 700 nm, hence is called P 700

(B) In PSI the reaction centre chlorophyll a has an absorption maxima at 680 nm and is called P 680

(C) The splitting of water molecule is associated with PS I

(D) Photosystems I and II are involved in Z scheme

(e) Lamellae of the grana have PS I and PS II and stroma lamellae membranes have PS II only.

Q.68 Read the following four statements (1 - 4): ***[AIPMT 2012]***

(1) Both photophosphorylation and oxidative phosphorylation involve uphill transport of protons across the membrane

(2) In dicot stems, a new cambium originates from cells of pericycle at the time of secondary growth

(3) Stamens in flowers of Gloriosa and Petunia are polyandrous

(4) Symbiotic nitrogen fixers occur in free-living state also in soil

How many of the above statements are right?

(A) Two (B) Three (C) Four (D) One

Q.69 In the overall process of photosynthesis, the number of CO_2, water, sugar and O_2 molecules utilized and produced is: ***[AMU 2012]***

(A) 12 (B) 13 (C) 19 (D) 31

Q.70 During Calvin cycle the total number of C02, ATP and NADPH molecules utilized and glucose, ADP and NADP molecules generated is: ***[AMU 2012]***

(A) 31 (B) 36 (C) 61 (D) 67

Q.71 Melvin Calvin was professor of: ***[AMU 2012]***

(A) Botany (B) Plant physiology (C) Chemistry (D) Biochemistry

Q.72 The essential element needed for water splitting in photosynthesis leading to O_2 evolution is: ***[AMU 2012]***

(A) Mo (B) Mn (C) Mg (D) K

Q.73 Non-cyclic photophosphorylation results in the production of: ***[J&K 2012]***

(A) ADP (B) ATP (C) NADPH (D) ATP and NADPH

Q.74 Photosynthetically active radiation (PAR) represents which of the following range of wavelength? ***[BHU 2012]***

(A) 500-600 nm (B) 450-950 nm (C) 340-450 nm (D) 400-700 nm

Q.75 Which elements are essential for the photophosphorylation? ***[AFMC 2012]***

(A) Mg and P (B) Zn and I (C) K and Cl (D) Mn and Cl

Q.76 Kranz anatomy is usually associated with: ***[AIIMS 2012]***

(A) C3 plants (B) C4 plants (C) CAM plants (D) C3 - C4 intermediate plants

Q.77 Which of the following statements regarding C_4 pathway is false? ***[Kerala 2012]***

(A) The primary CO_2 acceptor is phosphoenol pyruvate

(B) The enzyme responsible for CO_2 fixation is PEP case

(C) The mesophyll cells lack RUBISCO enzyme

(D) The C4 acid OAA is formed in the mesophyll cells.

(E) The bundle sheath cells contain the enzyme PEP case.

Q.78 Consider the following statements with respect to photosynthesis: ***[Kerala 2012]***

1. The first carbon dioxide acceptor in C_4 cycle is PGA

2. In C_3 plants, the first stable product of photosynthesis during dark reaction is RuBP

3. Cyclic photophosphorylation results in the formation of ATP

4. Oxygen which is liberated during photosynthesis comes from water

Of the above statements:

(A) 1 and 2 alone are correct (B) 1 and 3 alone are correct (C) 3 and 4 alone are correct

(D) 2 and 3 alone are correct (E) 2 and 4 alone are correct

ANSWER KEY

Objective Questions

Q.1 B	**Q.2** D	**Q.3** C	**Q.4** A	**Q.5** A	**Q.6** C
Q.7 B	**Q.8** B	**Q.9** D	**Q.10** D	**Q.11** A	**Q.12** D
Q.13 A	**Q.14** B	**Q.15** D	**Q.16** B	**Q.17** A	**Q.18** B
Q.19 D	**Q.20** C	**Q.21** C	**Q.22** C	**Q.23** A	**Q.24** B
Q.25 A	**Q.26** D	**Q.27** C	**Q.28** C	**Q.29** C	**Q.30** C
Q.31 D	**Q.32** B	**Q.33** B	**Q.34** B	**Q.35** B	**Q.36** C
Q.37 B	**Q.38** D	**Q.39** C	**Q.40** B	**Q.41** C	**Q.42** D
Q.43 B	**Q.44** A	**Q.45** A	**Q.46** D	**Q.47** A	**Q.48** D
Q.49 D	**Q.50** B	**Q.51** C	**Q.52** A	**Q.53** B	**Q.54** A
Q.55 A	**Q.56** A	**Q.57** B	**Q.58** B	**Q.59** D	**Q.60** C
Q.61 C	**Q.62** A	**Q.63** A	**Q.64** C	**Q.65** C	**Q.66** B
Q.67 A	**Q.68** C	**Q.69** A	**Q.70** C	**Q.71** C	**Q.72** B
Q.73 C	**Q.74** C	**Q.75** A	**Q.76** B	**Q.77** C	**Q.78** D
Q.79 B	**Q.80** C	**Q.81** D	**Q.82** C	**Q.83** B	**Q.84** C
Q.85 D	**Q.86** A	**Q.87** C	**Q.88** B	**Q.89** D	**Q.90** C
Q.91 C	**Q.92** C	**Q.93** A	**Q.94** A	**Q.95** D	**Q.96** B
Q.97 D	**Q.98** A	**Q.99** D	**Q.100** B	**Q.101** D	**Q.102** A
Q.103 D	**Q.104** C	**Q.105** B	**Q.106** B	**Q.107** D	**Q.108** D
Q.109 C	**Q.110** B	**Q.111** D	**Q.112** C	**Q.113** A	**Q.114** D
Q.115 B	**Q.116** A	**Q.117** B	**Q.118** B	**Q.119** C	**Q.120** B
Q.121 B	**Q.122** C	**Q.123** C	**Q.124** D	**Q.125** C	**Q.126** B
Q.127 A	**Q.128** C	**Q.129** D	**Q.130** B	**Q.131** B	**Q.132** A
Q.133 C	**Q.134** B	**Q.135** A	**Q.136** A	**Q.137** B	**Q.138** D
Q.139 D	**Q.140** B	**Q.141** B	**Q.142** B	**Q.143** A	**Q.144** C
Q.145 A	**Q.146** B	**Q.147** A	**Q.148** B	**Q.149** C	**Q.150** C

Q.151 B	**Q.152** A	**Q.153** A	**Q.154** C	**Q.155** C	**Q.156** A
Q.157 D	**Q.158** C	**Q.159** A	**Q.160** D	**Q.161** C	**Q.162** B
Q.163 D	**Q.164** A	**Q.165** A	**Q.166** A	**Q.167** B	**Q.168** B
Q.169 B	**Q.170** B	**Q.171** C	**Q.172** B	**Q.173** B	**Q.174** C
Q.175 C	**Q.176** B	**Q.177** D	**Q.178** B	**Q.179** C	**Q.180** A
Q.181 D	**Q.182** C	**Q.183** C	**Q.184** A	**Q.185** B	**Q.186** D
Q.187 D	**Q.188** B	**Q.189** B	**Q.190** A	**Q.191** C	**Q.192** B
Q.193 C	**Q.194** B	**Q.195** B	**Q.196** A	**Q.197** A	**Q.198** B
Q.199 B	**Q.200** A	**Q.201** A	**Q.202** C	**Q.203** A	**Q.204** B
Q.205 B	**Q.206** B	**Q.207** B	**Q.208** C	**Q.209** A	**Q.210** B
Q.211 C	**Q.212** B	**Q.213** D	**Q.214** B	**Q.215** A	**Q.216** D
Q.217 A	**Q.218** B	**Q.219** C			

Previous Years' Questions

Q.1 B	**Q.2** B	**Q.3** A	**Q.4** B	**Q.5** C	**Q.6** A
Q.7 A	**Q.8** A	**Q.9** D	**Q.10** D	**Q.11** B	**Q.12** A
Q.13 C	**Q.14** C	**Q.15** B	**Q.16** D	**Q.17** B	**Q.18** A
Q.19 A	**Q.20** D	**Q.21** C	**Q.22** A	**Q.23** A	**Q.24** D
Q.25 D	**Q.26** A	**Q.27** B	**Q.28** D	**Q.29** B	**Q.30** A
Q.31 A	**Q.32** C	**Q.33** D	**Q.34** B	**Q.35** D	**Q.36** A
Q.37 C	**Q.38** B	**Q.39** A	**Q.40** D	**Q.41** D	**Q.42** A
Q.43 D	**Q.44** A	**Q.45** D	**Q.46** C	**Q.47** C	**Q.48** A
Q.49 C	**Q.50** A	**Q.51** B	**Q.52** B	**Q.53** D	**Q.54** D
Q.55 A	**Q.56** A	**Q.57** A	**Q.58** A	**Q.59** D	**Q.60** B
Q.61 D	**Q.62** C	**Q.63** B	**Q.64** A	**Q.65** A	**Q.66** B
Q.67 D	**Q.68** A	**Q.69** D	**Q.70** D	**Q.71** C	**Q.72** B
Q.73 D	**Q.74** D	**Q.75** D	**Q.76** B	**Q.77** E	**Q.78** C