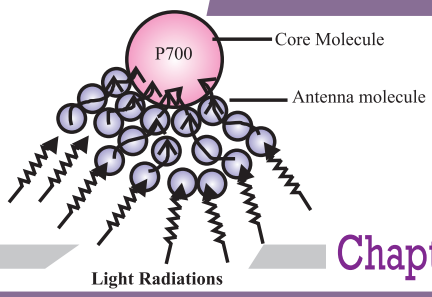


Chapter - 13

Photosynthesis in Higher Plants

Photosynthesis
Formation of glucose from CO_2 and water in presence of sunlight and chlorophyll.

Factors affecting photosynthesis
- **External factors**: Light, CO_2 conc., temperature, water, O_2 etc.
- **Internal factors**: Chlorophyll conc., leaf age, phytohormones etc.

Site of photosynthesis
Photosynthesis occurs in double membrane bound chloroplasts that consist of stroma, grana stacks, thylakoids and stroma lamellae. Thylakoids contain photosynthetic pigments.

Photosynthetic pigments
They include chlorophylls, carotenes and phycobilins. Chlorophylls are the major pigments while other two are accessory ones. They may be of various types and form two major pigment systems.
- **PS I**: Includes P_{700} as photocentre and LHC (light harvesing complex) with electron carriers.
- **PS II**: Includes P_{680} as photocentre and LHC.

Photosynthetic mechanism
An enzymatic anabolic reaction involving many intermediates.

Photochemical Phase
Light dependent phase occurring in thylakoids.
- **Photolysis**: Water molecule is broken down into O and H by absorbing light energy. It produces e^-.
- **Photophosphorylation**: Electrons released in photolysis of water are used for production of ATP through photophosphorylation. It may be of two types:
  - **Cyclic**: Involves only PS I and produces only ATP.
  - **Non-cyclic**: Involves both PS I and PS II and produces both ATP and NADPH.

Biosynthetic Phase
Light dependent reaction that occurs in stroma. It can be of three types.
- **C_3 cycle**: CO_2 combines with RuBP and produces glucose *via* many intermediate steps. Also called as Calvin cycle. 3C-phosphoglyceric acid is first stable product.
- **C_4 cycle**: Glucose is formed by CO_2 fixation but initial acceptor is PEP in mesophyll cells and first stable product is 4C compound oxaloacetic acid. C_4 plants have kranz anatomy and are more efficient than C_3 plants.
- **CAM cycle**: In xerophytes, CAM cycle is observed where CO_2 is fixed at night. Similar to C_4 plants, but two steps are separated by time (day and night) not in space. It helps in reducing transpiration.

Photorespiration
Light dependent oxygenation of RuBP and release of CO_2 in photosynthetic cells of plant. It involves chloroplasts, peroxisomes and mitochondria. It consumes energy and wastes the work of photosynthesis.

Points To Remember

Photosynthesis : Photosynthesis is an enzyme regulated anabolic process to manufacture organic compounds inside the chlorophyll containing cells from carbon dioxide and water with the help of sunlight as a source of energy.

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

Historical Perspective

Josheph Priestley (1770) : Showed that plants have the ability to take up CO_2 from atmosphere and release O_2. (Candle with bell jar and mouse expt.)

Jan Ingenhousz (1779) : Release of O_2 by plants was possible only in sunlight and only by the green parts of plants. (Expt. with aquatic plant in light & dark)

Theodore de Saussure (1804) : Water is an essential requirement for photosynthesis to occur.

Julius Von Sachs (1854) : Green parts in plant produce glucose which is stored as starch.

T.W. Engelmann (1888) : The effect of different wavelength of light on photosynthesis and plotted the first action spectrum of photosynthesis.

C.B. Van Niel (1931) : Photosynthesis is essentially a light dependent reaction in which hydrogen from an oxidisable compound reduces CO_2 to form sugar. He gave a simplified chemical equation of photosynthesis.

$$2H_2A + CO_2 \xrightarrow{\text{Sunlight}} 2A + CH_2O + H_2O$$

Hill (1937) : Evolution of oxygen occurs in light reaction.

Calvin (1954-55) : Traced the pathway of carbon fixation.

Hatch and Slack (1965) : Discovered C_4 pathway of CO_2 fixation.

Site for photosynthesis : Photosynthesis takes place only in green parts of the plant, mostly in leaves. Within a leaf, photosynthesis occurs in mesophyll cells which contain the chloroplasts. Chloroplasts are the actual sites for photosynthesis. The thylakoids in chloroplast contain most of pigments required for capturing solar energy to initiate photosynthesis : The membrane system (grana) is responsible for trapping the light energy and for the synthesis of ATP and NADPH. Biosynthetic phase (dark reaction) is carried in stroma.

Importance of Photosynthesis—(1) Synthesis of organic compounds (2) Change of radiant energy into chemical energy (3) Useful products are obtained from plants gums, oils timber fire wood, resins rubber, fibers and drugs, etc. (4) Balance the percentage of O_2 and CO_2 in atmosphere (5) Fossil fuels like coal, natural gas and petroleum have been formed inside the earth indirectly as a product of photosynthesis.

Pigments involved in photosynthesis :

Chlorophyll a : (Bright or blue green in chromatograph). Major pigment, act as reaction centre, involved in trapping and converting light into chemical energy. It is called universal photo-synthetic pigment.

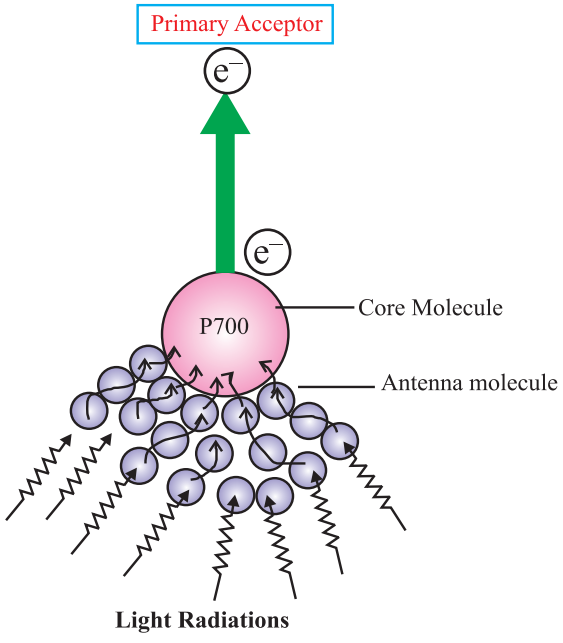
Chlorophyll b : Yellow green

Xanthophylls : Yellow

Carotenoids : Yellow to yellow-orange

- In the blue and red regions of spectrum shows higher rate of photosynthesis.

Light Harvesting Complexes (LHC) : The light harvesting complexes are made up of hundreds of pigment molecules bound to protein within the photosystem I (PS-I) and photosystem II (PS-II). Each photosystem has all the pigments (except one molecule of chlorophyll 'a') forming a light harvesting system (antennae). The reaction centre (chlorophyll a) is different in both the photosystems.



Light Harvesting Complex

Photosystem I (PS-I) : Chlorophyll 'a' has an absorption peak at 700 nm (P700).

Photosystem II (PS-II) : Chlorophyll 'a' has absorption peak at 680 nm (P680),

Process of photosynthesis : It includes two phases-Photochemical phase and biosynthetic phase. (Formerly known as Light reaction and dark reaction)

(i) **Photochemical phase (Light reaction) :** This phase includes-light absorption, splitting of water, oxygen release and formation of ATP and NADPH. It occurs in grana region of chloroplast.

(ii) **Biosynthetic phase (Dark reaction) :** It is light independent phase, synthesis of food material (sugars). (Calvin cycle). It occurs in stroma region of chloroplast.

Photophosphorylation : The process of formation of high-energy chemicals (ATP and NADPH) in presence of light.

Non-Cyclic photophosphorylation : Two photosystems work in series–First PSII and then PSI. These two photosystems are connected through an electron transport chain (Z. Scheme). Both ATP and NADPH + H^+ are synthesised by this process. PSI and PSII are found in lamellae of grana, hence this process is carried here.

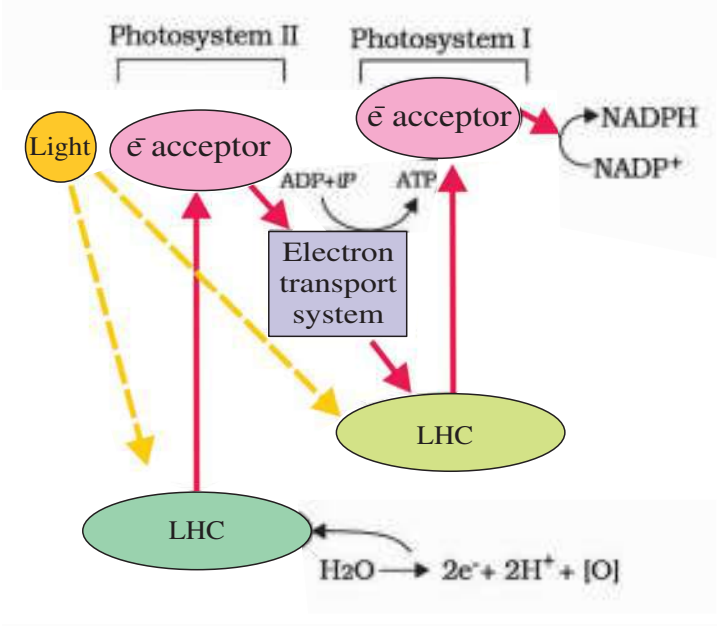


Figure 13.5 Z scheme of light reaction

The electron transport (Z-Scheme) : In PS II, reaction centre (chlorophyll a) absorbs 680 nm wavelength of red light which make the electrons to become excited. These electrons are taken up by the electron acceptor that passes them to an electron transport system (ETS) consisting of cytochromes. The movement of electron is down hill. Then, the electron pass to PS I and move down hill further to $NADP^+$. $NADP^+$ in then reduced to $NADPH + H^+$.

The splitting of water : It is linked to PS II. Water splits into H^+, [O] and electrons. $2H_2O \longrightarrow 4H^+ + O_2 + 4e^-$

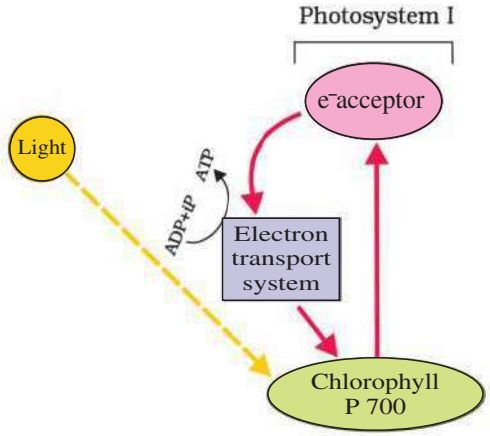
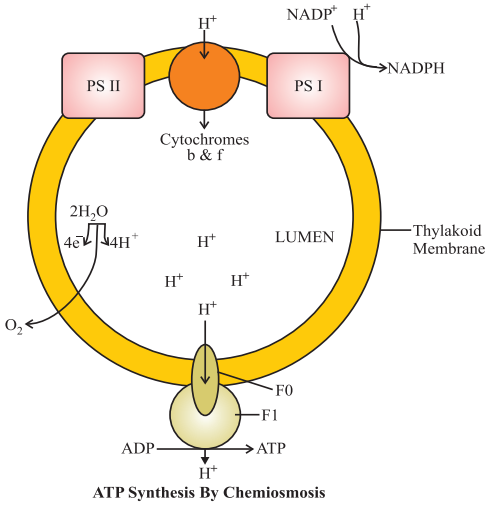


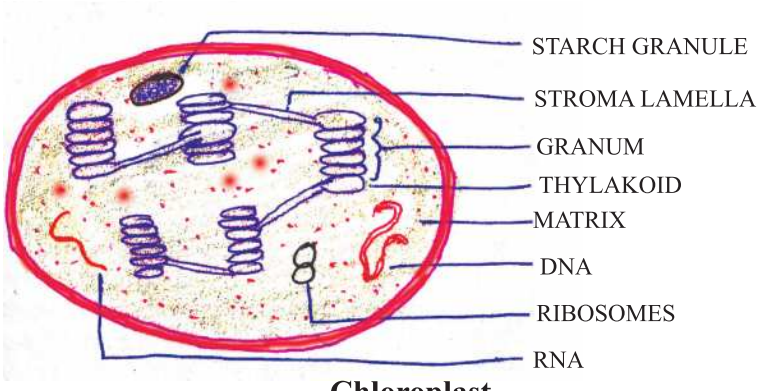
Figure 13.6 Cyclic photophosphorylation

Cyclic photophosphorylation : Only PS-I works, the electron circulates within the photosystem. It happens in the stroma lamellae (possible location) because in this region PSII and NADP reductase enzyme are absent. Hence only ATP molecules are synthesised. It occurs when only light of wavelengths beyond 680 nm are available for excitation.

Chemiosmotic Hypothesis : Chemiosmotic hypothesis explain the mechanism of ATP synthesis in chloroplast. In photosynthesis, ATP synthesis is linked to development of a proton gradient across a membrane. The protons are accumulated inside of membrane of thylakoids (in lumen). ATPase enzyme has a channel of that allow diffusion of protons back across the membrane. This release energy to activate ATPase enzyme that catalyses the formation of ATP.



ATP Synthesis By Chemiosmosis



Chloroplast

Biosynthesis phase in C_3 plants :

ATP and NADPH, the products of light reaction are used in synthesis of food. The first CO_2 fixation product in C_3 plant is 3-phosphoglyceric acid or PGA. The CO_2 acceptor molecule is RuBP (ribulose bisphosphate). The cyclic path of sugar formation is called Calvin cycle on the name of Melvin Calvin, the discover of this pathway. **Calvin cycle** proceeds in three stages.

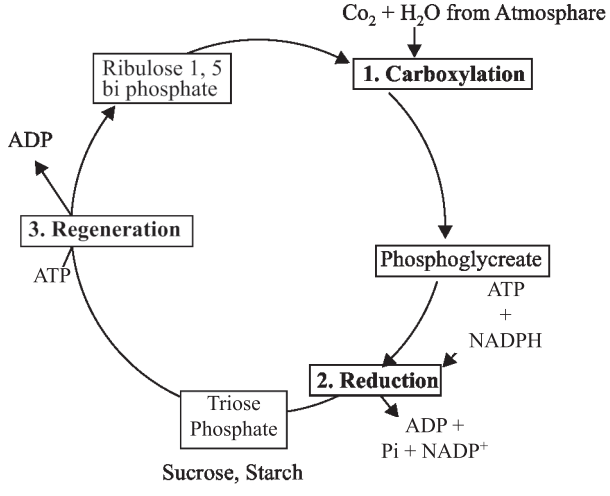
(1) Carboxylation : CO_2 combines with ribulose 1, 5-bisphosphate to form 3 PGA in the presence of RuBisCo enzyme (present in stroma)

(2) Reduction : Carbohydrate is formed at the expense of ATP and NADPH.

It involves 2ATP for phsophorylation and 2NADPH for reduction per CO_2 molecule fixed.

(3) Regeneration : The CO_2 acceptor ribulose 1, 5-bisphosphate is formed again.

6 turns of Calvin cycles and 18 ATP molecules are required to synthesize one molecule of glucose.



$$6CO_2 + 6\,RuBP + 18ATP + 12NADPH \longrightarrow C_6H_{12}O_6 + 6RuBP + 18ADP + 18P\boldsymbol{i} + 12NADP$$

Input	Output
$6CO_2$	One Glucose
18 ATP	18 ADP
18NADPH	12 NADP

The C4 pathway : C_4 plants such as maize, sorghum, sugarcane have a four carbon compound special type, of leaf anatomy, they tolerate higher temperatures. In this pathway, oxaloacetic acid (OAA) is the first stable product formed. It is 4 carbon atoms compound, hence called C_4 pathway (Hatch and Slack Cycle). The leaf has two types of cells : mesophyll cells and bundle sheath cells (Kranz anatomy). Initially CO_2 is taken up by phosphoenol pyruvate (PEP) in mesophyll cell and changed to oxaloacetic acid (OAA) in the presence of PEP carboxylase. Oxaloacetate is reduced to maltate/asparate that reach into bundle sheath cells.

The decarboxylation of maltate/asparate occurs with the release of CO_2 and formation of pyruvate (3C). In high CO_2 concentration RuBisCO behaves as carboxylase and not as oxygenase, hence the photosynthetic losses are prevented. RuBP operates now under Calvin cycle and pyruvate transported back to mesophyll cells and changed into phosphoenol pyruvate (PEP) to keep the cycle continue.

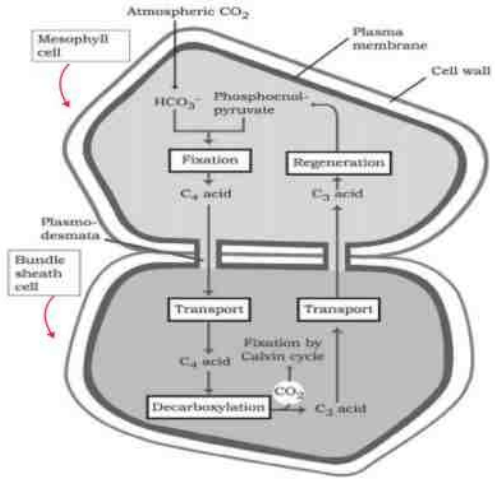


Figure 13.9 diagrammatic representation of the Hatch and Slack Pathway

Photorespiration : The light induced respiration in green plants is called photorespiration. In C_3 plants some O_2 binds with RuBisCO and hence CO_2 fixation is decreased. In this process RuBP instead of being converted to 2 molecules of PGA binds with O_2 to form one molecule of PGA and phosphoglycolate.

$$RuBP + O_2 \xrightarrow{RuBP} PGA + Phosphoglycolate$$

There is neither synthesis of ATP nor $NADPH_2$ or sugar. Rather it results in release of CO_2 with utilisation of ATP. The biological function of photorespiration is not known yet.

C_4 Plants :

(1) Lack Photorespiration

(2) Show response to high light intensities

(3) Have greater productivity of biomass.

Adaptations in C_4 Plants :

(i) Kranz Anatomy

(ii) Occurrence of two types of cells

(iii) Dimorphic chloroplast

(iv) Presence of RuBisCO in Bundle Sheath cells and PEPcase in mesophyll cells.

(v) Mechanism to increase CO_2 concen-tration near RuBisCO in Bundle Sheath cells.

CAM (Crassulacean Acid Metabolism) Plants—Stomata open at night. *e.g.,* Cacti, Bryophyllum, Pineapple.

Law of Limiting Factors : If a chemical process is affected by more than one factor, then its rate will be determined by the factor which is nearest to its minimal value. It is the factor which directly affects the process if its quantity is changed. Factors affecting photosynthesis :

1. **Light :** Rate of photo-synthesis increases at low light intensities. At high intensities of light beyond a point the rate of CO_2 fixation decreases. Longer hours of light duration favour more photosynthesis rate.
2. **Carbon dioxide :** Increase in CO_2 concentration causes increases in CO_2 fixation. It is the major limiting factor for photosynthesis.
3. **Temperature :** The rate of photosynthesis at optimum temperature is, high. It is 20°C-25°C For C_3 plants and 30-45°C for C_4 plants.
4. **Water :** Water is one of the reactant in photosynthesis, but it effects the rate of CO_2 fixation. Low water content causes the stomata to close and reduces the CO_2 availability.

Questions

(SRT) Select Response Type Question (1 mark each)

1. Which of the following pathway is following by Pineapples in order to fix carbon-di-oxide efficiently?
   (a) TCA cycle (b) CA cycle
   (c) CAM pathway (d) C3 cycle
2. How many molecules of ATP are required for synthesis of one molecules of glucose in C3 and C4 pathway?
   (a) 12 and 18 respectively (b) 30 and 18 respectively
   (c) 16 and 30 respectively (d) 18 and 30 respectively
3. As the light intensity increases, the rate of photosynthesis increases. During high light intensities the rate of photosynthesis decreases due to
   (a) Increase incident light beyond a point causes the breakdown of chlorophyll
   (b) Increase incident light beyond a point causes less absorption of minerals
   (c) Increase incident light beyond a point will block xylem vessels
   (d) Increase incident light beyond a point will use carbon-di-oxide and will not be available for photosynthesis.

CONSTRUCTED RESPONSE TYPE (CRT)

Very Short Answer Questions (1 marks each)

4. Which one of the photosystems can carry on photophosphorylation independently ?
5. Name two photosynthetic pigments belonging to carotenoids.
6. Name the most abundant enzyme found in the world.
7. Name the scientist who proposed the C_4 pathway. Name one such plants.
8. Where does carbon fixation occur in chloroplast ?
9. Which compound acts as CO_2 acceptor in Calvin cycle ?
10. Name the end products of light reaction.
11. Does the photosynthesis occur in moon light ? Why ?
12. Which part of sunlight is most suitable for photosynthesis.

Short Answer Questions-I (2 marks each)

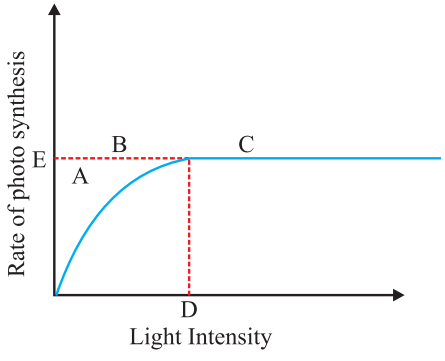
13. Why does the rate of photosynthesis decline in the presence of continuous light ?
14. Why do green plants start evolving carbon dioxide instead of oxygen on a hot sunny day ?
15. Fill in the space, left blank in the given table to bring the difference between C_3 and C_4 plants :

S.No.	Characteristics	C_3 plants	C_4 plants
1.	Cell type	mesophyll	...(a)... and mesophyll
2.	CO_2 acceptor	...(b)...	Phosphoenol pyruvate (PEP)
3.	First CO_2 fixation product	3-PGA	...(c)...
4.	Optimum temperature	...(d)...	30° C to 45° C

16. State two functions of accessory pigments, found in thylakoids.
17. Why do C_4 plants are more expensive (in energy requirement) than C_3 plants ?
18. What is limiting factor ? State the law of limiting factors.

Short Answer Questions-II (3 marks each)

19. The figure shows the effect of light on the rate of photosynthesis. Based on the graph, answer the following questions :
    (i) At which point(s) A, B or C in the curve, light is a limiting factor ?
    (ii) What could be the limiting factor(s) in region A ?
    (iii) What do region C and D represent on the curve ?

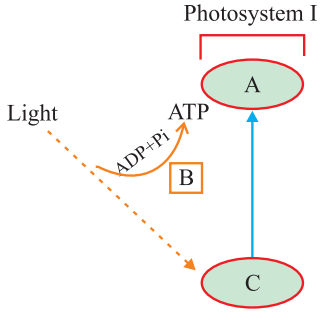


20. When and why does photorespiration take place in plants ? How does this process result in a loss to the plant ?

21. What are the steps that are common to C_3 and C_4 photosynthesis ?

22. Two potted plants were kept in an oxygen free environment in transparent containers, one in total darkness and the other in sunlight. Which one of the two is likely to survive more ? Justify your answer by giving the reason.

23. (a) In the diagram shown below, label A, B and C. What type of phosphorylation is possible in this ?



(b) Give any two points of difference between cyclic and non-cyclic photophosphorylation.

24. Name the pigment found in tomato, carrots, chillies etc. which gives red colour to them. Is it a photosynthetic pigment ?

25. Chloroplast and mitochondria are believed to be semi-autonomous organelles. Justify the statement.

26. Mention the conditions under which the C_4 plants are superior to C_3 plants.

Long Answer Questions (5 marks each)

27. Describe C_4 pathway in a paddy plant. How is this pathway an adaptive advantage to the plant ?

28. Explain, the process, of biosynthetic plase of photosynthesis occurring in chloroplast.

29. (a) Give steps to ATP synthesis in chloroplasts through chemiosmosis.
(b) Schematically represent non-cyclic photophosphoryation in plants.

Answers

(SRT) Select Response Type Question (1 mark each)

1. (c) CAM pathway

2. (d) 18 and 30 respectively
3. (a) Increase incident light beyond a point causes the breakdown of chlorophyll

CONSTRUCTED RESPONSE TYPE (CRT)

Very Short Answer (1 mark each)

4. PS-I.
5. Carotene and xanthophylls.
6. RuBisCO.
7. Hatch and Slack. Maize and Sorghum.
8. Carbon fixation takes place in stroma.
9. Ribulose 1, 5 bisphosphate.
10. ATP, NADPH and O_2.
11. No, the moonlight is unable to perform light reactions of photosynthesis (ATP-NADPH Synthesis as it is 1/50,000 the intensity of sunlight and not strong enough to enable plants to photsynthesise.
12. Blue and Red regious of light spectrum.

Short Answers-I (2 marks each)

13. Increase incident light beyond a point causes the breakdown of chlorophyll.
14. On a hot suny day, enzyme RuBP carboxylase becomes active and its affinity for CO_2 decreases and for O_2 increases. Consequently more and more photosynthetically fixed carbon is lost by photorespiration.
15. (a) Bundle sheath
    (b) RuBP
    (c) OAA (oxaloacetic acid)
    (d) 20°C-25°C
16. (a) Absorption of light and transfer of energy to chlorophyll 'a'.
    (b) Protect chlorophyll 'a' from photo oxidation.
17. Because they require more energy (30 ATPs) in synthesizing one glucose molecule as compared to C_3—(18ATPs).

18. Limiting Factor—A factor which is deficient to such an extent that increase in its concentration directly increase the rate of the process.

(For the law of limiting factors see text in NCERT Book.) Page 222

Short Answers-II (3 marks each)

19. (i) 'B'

(ii) CO_2 and temperature

(iii) 'C' represents to constant rate of photosynthesis, 'D' is the light saturation intensify at which rate of photosynthesis is maximum.

20. Refer NCERT, Text Book Biology for class XI.

21. **Hints :**

(a) Photolysis of H_2O and photophosphorylation occurs in both C_3 and C_4 plants.

(b) In both, dark reaction occurs in stroma.

(c) Calvin cycle results in the formation of starch in both the plants.

(d) During dark reaction both types of plants undergo the phases of carboxylation and regeneration :

22. **Hints :**

- The plant in sunlight will survive for longer period.
- Light is essential for photosynthesis.

23. (a) (A) e^- acceptor

(B) Electron transport system

(C) Chlorophyll P700

(b) NCERT Text Book of Biology for Class XI.

24. **Carotenoid :** It is an accessory photosynthetic pigment which takes part in harvesting light energy only if chlorophyll is present.

25. Mitochondria and chloroplast both contain DNA and can reproduce independently of the cell and chloroplasts even have a built in feeding mechanism both have their own ribosomes of 70S type and capable of synthesising their own kind of proteins.

26. C_4 Plant grow in regions with high temperatures and intense light. The rate of transpiration in C_4 plant is 25% of a C_3 plant, thus they conserve water and have greater photosynthetic rate gives greater rate of growth in intense sunshine and high temperature.

Long Answers (5 marks each)

27. NCERT Text Book of Biology for Class XI.

28. Refer Points to Remember.

    Hints : Three stages of Calvin cycle : Carboxylation, Reduction and Regeneration.

29. (a) Chemiosmotic Hypothesis, NCERT Text Book of Biology for Class XI.

    (b) Z-Scheme of light reaction, NCERT Text Book of Biology for Class XI.

Assertion Reasoning (1 mark each)

The following question consists of 2 statements - Assertion (A) and Reason (R). answer the question by selecting the appropriate option below :

(a) Both A and R are true and the reason is a correct explanation of the assertion

(b) Both A and R are true and the reason is not a correct explanation of the assertion

(c) The assertion is true but the reason is false

(d) Both the assertion and reason are false

(e) The assertion is false but the reason is true

30. **Assertion (A) :** C4 cycle is found in CAM plants.

    Reason (R) : Photorespiration does not occur in C4 plants.

31. **Assertion (A) :** Higher the concentration of O_2 in the atmosphere, lower is the photosynthesis are.

    Reason (R) : Lower respiration rate is due to oxidation of RuBisCo.

32. **Assertion (A) :** For the formation of one molecule of glucose, 6 molecules of CO_2 and 12 molecules of $NADPH^+ + H^+$ and 18 ATP are used.

Reason (R) : In light reaction ATP and $NADPH_2$ are formed.

Solution:

Assertion Reasoning

30. (e)

31. (a)

32. (b)

Source-based/Case-based/Passage-based/Integrated assessment question (4 marks each)

Read the following and answer any four questions from (i) to (v) given below :

33. Photosystems are of two types, PS I and PS II, and are found in thylakoid membranes. Each photosystem consists of a light harvesting complex and each LHC is made up of hundreds of pigment molecules bound to proteins. Each photosystem has all the pigments complexes except one molecule of chlorophyll a.,a single chlorophyll forms a reaction centre. Each photosystem absorbs different wavelengths of light. In PS I the reaction centre chlorophyll a has an absorption peak at 700 nm, hence is called P700, while in PS II it has absorption maxima at 680 nm, and is called P680. It was named PSII because it was discovered after PSI was discovered. Only light reaction takes place in these systems. PSII is the first system which traps light and the most important function is splitting of water and molecular oxygen. The electron is released while the splitting of water. These electrons are passed through PSII and PSI before ending up in NADPH as they move down in the electron transport chain. NADPH, thus produced is used in the dark reaction of photosynthesis.

(i) Photosystem I and II respectively are found in _____

(a) Inner and outer surface of thylakoid in mitochondria

(b) Outer and inner surface of thylakoid in mitochondria

(c) Inner and outer surface of thylakoid in chloroplast

(d) Outer and inner surface of thylakoid in chloroplast

(ii) Will photolysis of water occur in PSI? (Yes/No)

(iii) What is the correct sequence?

I. Antenna molecule 700

II. NADPH

III. PSI

IV. PSII

V. Thylakoid membrane

(a) I, II, III, IV, V

(b) II, III, IV, I, V

(c) V, IV, III, I, II

(d) V, III, IV, I, II

(iv) The dark reaction cannot take place during the day. (True/False)

(v) Which one of the following is not true about the light reaction in photosynthesis?

(a) Photosystems are arrangements of chlorophyll and other pigments packed into thylakoids

(b) Photolysis of water occurs in PSI

(c) NADP is reduced

(d) Magnesium ions are required for the formation of chlorophyll

Solution:

Source-based/Case-based/Passage-based/Integrated assessment questions

33. (i) (d) Outer and inner surface of thylakoid in chloroplast

(ii) No

(iii) (c) V, IV, III, I, II

(iv) False (dark reaction takes place both during the day and the night)

(v) (b) Photolysis of water occurs in PSI